4

WIRELESS SYSTEMS AND TECHNOLOGY

Wireless technology is on the verge of creating a revolution in communications. While systems such as broadcast radio and television have been around for many years, many new types of wireless communication systems are emerging such as digital cellular, personal communications services (PCS), and packet radio.

Wireless systems and technologies can be classified in many different ways. They can be either terrestrial- or satellite-based. They can be classified by the type of primary user service that can be provided such as one-way, two-way, or multiple-way voice, video, or data. Another form of classification is whether they are a traditional analog or digital system. Yet another way is whether they utilize existing or emerging technologies. All of the various types of classifications have their respective merits and limitations. Wireless systems and technologies elude a single, all encompassing, universal method of classification. For this reason, the systems and technologies presented here are not classified. One exception to this, however, is the category of wireless telephone systems. These are wireless systems whose primary function is to provide a wireless access to the wireline telephone network.

This section presents a wide variety of both existing and emerging wireless systems and technologies. These systems and technologies include land mobile radio, HF radio, broadcast radio and television, and multichannel multipoint distribution service; wireless telephone systems such as cellular and PCS systems; paging; packet radio; wireless local area networks; wireless digital modems; and satellite-based systems. Descriptions of these systems and technologies are presented with particular emphasis on applications in rural areas. Example costs of wireless systems and services are given where applicable. Frequency allocations for the various wireless systems operating in the United States are presented.

When considering operating a wireless system in a specific rural area, radio spectrum must be available for that system to operate. While listings of operating licenses gives some good information about the use of the radio spectrum throughout locations of interest, measurements of spectrum usage are perhaps the best indicator of available spectrum. Appendix B shows radio spectrum measurements made by the Institute for Telecommunication Sciences (ITS) in Eureka, California, a rural area on the coast of the Pacific Ocean. These measurements were taken over the 108 MHz to 19.7 GHz range and provide insight into the potential availability of spectrum in a rural area. Although these measurements show a good example of spectrum usage in a rural area, spectrum usage in other rural areas may be different. This may be especially true for areas that differ in geography and climate from Eureka such as the Midwestern plains or the Southwestern desert.

4.1 Land Mobile Radio

Land mobile radio (LMR) consists of a wide variety of mobile radio systems, ranging from a simple pair of handheld citizen band (CB) "walkie-talkies" to elaborate radio repeater systems with paging and telephone interconnect. Land mobile radio is distinguished from other mobile radio services, such as aeronautical mobile radio (communications with aircraft), maritime mobile radio (communications with ships at sea), and the new mobile satellite service (mobile communications via satellites). LMR includes radio service between mobile units or between mobile units and a base station. LMR is licensed by the Federal Communications Commission (FCC) under several categories, including:

1) private radio (where the owner is licensed for a particular frequency and owns and operates exclusively within his own system),

2) Part 95 Personal Radio (CB; where the owner operates within a set of 40 frequencies near 27 MHz, owning and operating his equipment, but also talking with other CB users), and

3) the new Commercial Mobile Radio Service (CMRS; where the user owns his radios, but subscribes to repeater and other services provided by a system operator).

These CMRSs are also called Specialized Mobile Radio (SMR) services. Not included in LMR is cellular telephone service, which is considered (from a regulatory standpoint) an extension of the common carrier telephone system. The rules governing CMRS are a recent change, reflecting the continually more blurred distinction between SMR and cellular telephone services.

LMR typically offers a two-way analog voice channel with 15-30 kHz of channel bandwidth. Some systems can be modified to use a modem to transfer digital information, provide fax services, or provide remote control of various devices.

Mobile radio, CB radio, SMR, and amateur mobile radio fill a general need for mobile and personal communications that has significant implications for business productivity, personal safety, and social connection. In most rural areas, business must be conducted over a widespread area, and other forms of communication (e.g., cellular phones, paging, phone booths, etc.) are less available. This applies directly to the farmer, rancher, and forester; but it also applies to the suppliers, laborers, and buyers who need to do business with them. Traffic accidents or farm accidents often occur when other people are not present, so radio is often the first means of bringing help and notifying others of the problem.

Some rural areas currently do not have access to cellular or SMR systems, which leaves LMR as the major means of mobile/personal communications. Fortunately, LMR channel licenses are generally easily available, since there is less competition for such licenses than in urban areas. These channels will probably be in the private radio service. For low end service, CB is available near 27 MHz. In larger communities, there may be a local repeater system, providing service through the CMRS. SMR services have been growing rapidly, partly because of the substantially improved coverage provided to the customer and partly because of the improved spectrum efficiency that SMR allows.

A typical mobile radio system is purchased by a private businessman/farmer/rancher, who uses it to communicate with the home or office while out on the road or the farm. An investment of $300 to $1000 provides a base station transmitter and a mobile or portable radio, to achieve communications over a 10-20 mile range. Usually, there will be no phone patch capability, though it can be done (poorly, since there is at least a push-to-talk requirement, which may require a 3rd party at the telephone to operate).

Simplex and duplex radio

There are several types of mobile radio operation, each of which is particularly suited for certain applications. The most basic of these types of operation is simplex radio. In simplex radio, all radios in a system transmit and receive on the same frequency (shown as F1 in Figure 4-1). A person can communicate with a single listener or a group of listeners by turning on his transmitter and talking. All users who have radios turned on and tuned to that frequency will hear the person transmitting. For convenience, most radios have a push-to-talk switch on the microphone;

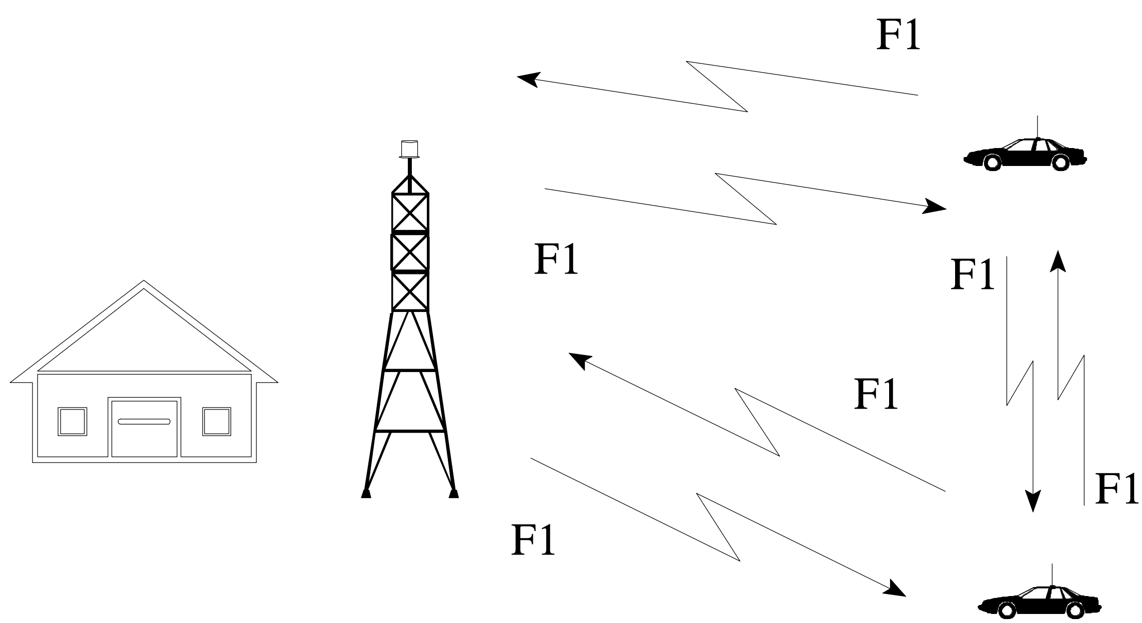

Figure 4-1. Diagram of a simplex radio system.

holding the switch down activates the radio transmitter. When the person transmitting is finished talking, he releases the switch and the radio reverts to its normal receiving mode. A conversation between two people requires the observance of a certain discipline, since both people must not talk (i.e., transmit) at the same time. Instead, they must carefully alternate between listening (receive mode) and talking (transmit mode).

Simplex radio is ideal for dispatch service, where a single dispatcher at a base station provides direction to a fleet of mobile workers. Each mobile unit can hear instructions from the dispatcher, as well as all replies from other mobile units. Dispatch service is typically used in delivery, service, taxi, and police operations. If it is important that messages be delivered to a particular mobile unit, but not to the others, tone-coded squelch can be used. This technique sends a coded signal along with each transmission that causes certain radios to ignore the transmission, depending on whether the coded signal matches the code stored in each radio. Tone-coded squelch is often used when several systems share the same frequency. In particular, it prevents users of one system from being distracted by messages intended for users of another system, and vice versa.

Simplex radio is used in most mobile radio bands because it provides the cheapest and simplest system. Only a single frequency is needed (this is important when there is a shortage of frequencies), and operation is straightforward. However, simplex radio has some limitations, some of which can be solved by using duplex radio systems. Duplex radio uses two frequencies; each radio transmits on one frequency and receives on another. With full-duplex radio systems, each radio can simultaneously transmit and receive, making full continuous two-way conversations possible, without the use of push-to-talk operation. Cellular telephones and cordless phones are examples of full-duplex systems. Half-duplex radios transmit on one frequency and receive on another, but not simultaneously. Although half-duplex radios require push-to-talk operation, they offer advantages in some situations, particularly in repeater operation (discussed in the next section). When half-duplex radios are used in dispatch operations, the base station normally transmits on one frequency and all mobile units transmit on the other frequency. This means that a mobile unit can hear the base station (dispatcher), but it cannot hear the replies from the other mobile units.

Mobile radio is useful especially when it can provide service to the entire geographic area in which the user normally operates. In rural areas, markets for services can be dispersed over large areas, which make long range operation very useful. The coverage area of a transmitter can be increased by increasing the transmitter power or by raising the transmitting and receiving antennas. Usually the base station antenna is placed on a high tower, but the mobile antenna must remain low for obvious practical reasons. The mobile transmitter power may also be somewhat limited for practical reasons. Assuming, for example, operation at 150 MHz with a 300-ft antenna tower and 25-watt base station and mobile transmitters, good two-way communications can be maintained with the base station over a range of approximately 30 miles depending on terrain. Mobile-to-mobile communications would typically operate over only about 7 miles. Since the coverage area is proportional to the square of the range, the coverage area from the base station tower is 20 times larger than from a car. The high antenna tower is the key to getting acceptable operational range without using excessively high transmitter power. High power transmitters are costly, have large AC power requirements, and are prone to reliability problems.

Using a high antenna tower is also quite expensive but avoids the AC power and reliability problems.

Repeaters

A repeater provides an excellent option for users of a mobile radio system who cannot provide their own high antenna tower. The repeater is a radio device that receives a signal on frequency F1 and simultaneously re-transmits the signal on frequency F2. Figure 4-2 depicts the operation of a repeater. Radio User A transmits a signal to Radio User B on frequency F1. The repeater

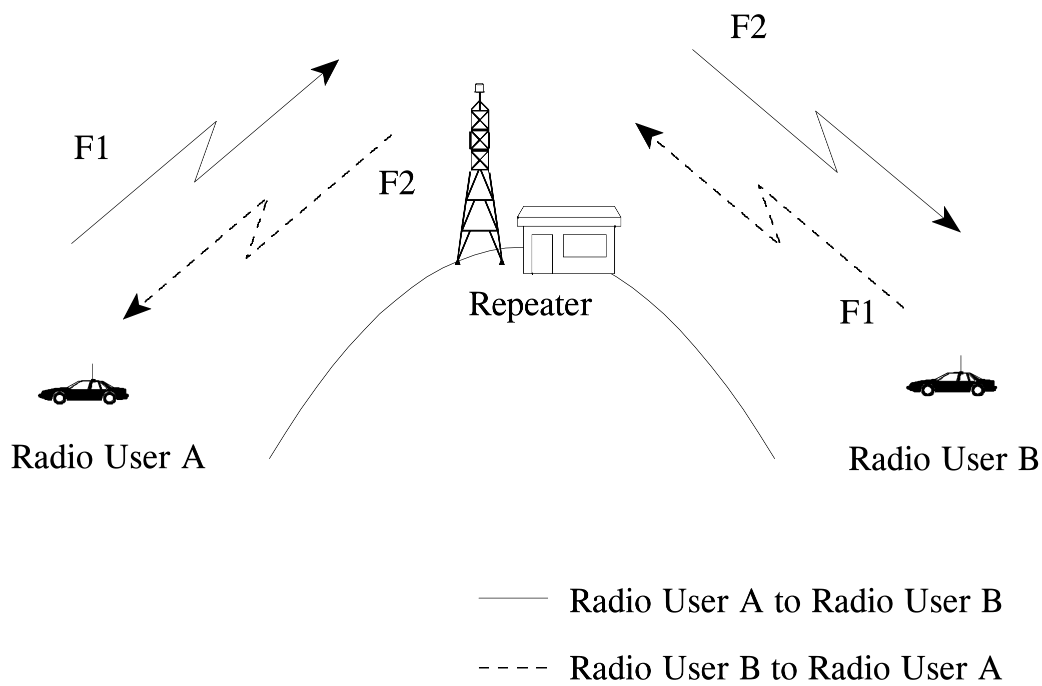

Figure 4-2. Operation of a radio repeater.

picks up the signal on frequency F1 and retransmits the signal on frequency F2. Radio User B listens continually on frequency F2 and hears the signal on frequency F2 when it is retransmitted by the repeater.

If Radio User B wants to send a signal to Radio User A, the same procedure is followed. Thus, for all repeater customers, the rule is to always transmit messages on frequency F1 and to listen for messages on frequency F2. As long as Radio User A and Radio User B are both in range of the repeater, the process will work. Since the repeater is located on a high tower, it can receive signals from Radio User A and Radio User B, even when they use relatively low antennas and low transmitter power. Instead of requiring each radio user to build a high antenna tower, a single tower is beneficially shared among all of them.

Specialized mobile radio

The radio repeater operation previously described is used for SMR systems. The SMR operator will typically charge customers a flat rate of $10-$15 per month for the use of the repeater. Since a given customer will typically use the radio only a few minutes each day, the SMR operator can rent the repeater to several customers. The only problem occurs when two customers want to use the repeater at the same time. If customer A is using the system when customer B tries to use the system, customer B will be "blocked" from using the repeater until customer A finishes. As long as blockage does not occur too often, customers may consider the service to be satisfactory. As more customers are added to the repeater service, blocking will be more likely to occur.

Trunked repeaters

When a single repeater becomes too busy, the SMR operator can add another repeater to the tower (using frequencies F3 and F4) and put half his customers on the new repeater channel. The process of adding repeater channels and designating a particular channel for each customer can be continued as the number of customers increases. However, an examination of the statistics of blocking suggests a better strategy. Instead of assigning a particular customer to a particular repeater channel, each customer in a trunked system can choose any repeater channel that is unused at the moment. This technique greatly decreases the amount of blocking, since blocking occurs only when all repeater channels are in use. Previously, blocking would occur whenever a customer's designated channel was busy.

Though the details of system operation are somewhat complex, a trunked repeater system automatically assigns a customer to any unused repeater channel. The SMR operator needs to buy somewhat more expensive and complex repeater equipment, but can serve more customers with fewer total number of repeater channels.

Many trunked repeater systems can also provide telephone connections. Instead of retransmitting the signal received on frequency F1, the repeater changes its mode of operation. Signals received on frequency F1 by the repeater are connected to a telephone line and sent to a telephone. Instead of retransmitting signals (received on frequency F1) on frequency F2, the repeater transmits signals from the telephone line on frequency F2. The user in the car listens to the telephone on frequency F2 and transmits to the telephone on frequency F1. SMR telephone interconnect capabilities are particularly useful in rural areas where cellular telephone is not available. Depending on the particular SMR equipment capabilities, the telephone interconnect may operate only in the half-duplex mode, which requires a push-to-talk operation by the SMR user.

Enhanced SMR (ESMR)

ESMR is a name applied to a class of SMRs that use advanced digital vocoders and provide enhanced user services. One example ESMR system uses a digital vocoder and time-division multiple access (TDMA) technology to squeeze six voice channels into a 25-kHz bandwidth. (TDMA is discussed in more detail in the Wireless Telephone Systems section of this report.) ESMR systems provide a wide range of telephone, dispatch, and possibly paging, fax and data services. ESMRs are built using large numbers of sites, whose individual range is often deliberately limited to obtain a higher degree of frequency reuse.

SMR systems in rural areas

In crowded urban areas, SMR is particularly valuable because of the larger number of customers that can be served with fewer crowded radio channels. In sparsely populated rural areas, SMR provides a higher level of service at reduced total expense; this service is particularly valuable since alternative services (like cellular telephone) may not be available. SMR services are aimed particularly at the businessman and the tradesman. In rural areas, this would include repair and delivery operations, implement dealers, agricultural supply and feed businesses, and trucking/transportation services. SMR services are typically priced at $10/month for unlimited airtime using repeater services, with an airtime charge (e.g., $0.25/minute) for telephone interconnect. One major disadvantage of SMR service is that customers must buy their own radios, which typically cost $700-$1200.

These SMR operations provide inexpensive two-way radio service between the home and car or between the shop and the service vehicle, typically within a 25- to 35-mile radius. For operations with multivehicle fleets, SMR service provides dispatch operations, where the vehicles can hear all conversations between the vehicles and the dispatcher. When the SMR allows telephone interconnection, half-duplex or full-duplex operation is usually available. Full-duplex operation, however, requires more expensive radios than are necessary for half-duplex operation.

Many rural SMRs started as small “mom-and-pop” operations, but these smaller operations have often been bought out and merged into statewide operations. For example, one organization has more than 100 SMR sites covering all of Iowa, much of Minnesota, and parts of several neighboring states. These operations are statewide only to the degree that a truck (for example) calling the home office from anywhere in the state (or even outside the state, for that matter) could contact a repeater. However, the multiple repeater sites are not integrated nor interconnected except through the telephone system. If the repeater were out of range of the home office, there would be no one for the truck driver to talk with. Instead of using the SMR repeater to talk directly with the home office, the truck driver would use the telephone interconnect mode to connect to the telephone system at the SMR site nearest to him, then use a credit card to make a long distance call to the home office.

SMR service is currently available in most rural areas. A number of SMR companies are already planning the next step of constructing large ESMR systems, in urban and rural areas alike. When these systems are in place, mobile users will have a substantial set of services available to them, including fax, mobile data, E-mail, and digital voice. The disadvantage is that these radios will initially cost $2000-$3000 each.

LMR frequency bands

Mobile radio is available in a wide range of frequency bands; the choice of radio bands is determined mostly by cost, reliability, coverage distance, and type of services desired. As a rule, the lower frequencies provide a longer range service, but require larger antennas. Otherwise, many bands can be considered interchangeable. Some features of the individual bands are summarized below.

CB radios operate in the 27 MHz band. They are inexpensive and widely available in electronic equipment stores. A pair of handheld 1-watt units can be purchased for less than $100, which will typically give simplex voice communications over a 1-mile path. Base station and mobile installations can operate with up to 5 watts of transmitter power, and may provide communications over a range of 20 miles. A major problem with interference occurs because signals can travel for hundreds of miles under certain environmental conditions, causing a large number of signals and noise from thunderstorms to be transported from hundreds of miles away. An estimated one million CB radios are sold each year, and five million people actively use CB radios. CB radios are often used by truck drivers and other drivers to check on road conditions and the presence of police. Many state highway patrols routinely monitor Channel 9, listening for requests for assistance or reports of accidents.

The 30-50 MHz band, also called the VHF low-band, has enhanced long-range capabilities, but is also impacted by intermittent noise and interference problems. One of the first bands to be used extensively for mobile radio, especially by state police cars, it is now more lightly used. Only a few manufacturers produce modern equipment for this band.

The 151-162 MHz band is extremely crowded in major urban areas, but relatively clear frequencies are usually available in rural areas. Similarly, the 450-470 MHz band is also quite crowded in urban areas, but clear frequencies should be available in most rural areas. Trunked repeater operation is not permitted in these bands at present. A current study by the FCC will probably lead to major changes in regulations and technical operation for these bands. Such changes will probably include a narrowing of bandwidths and encouragement of trunked systems and SMR.

The 218-220 MHz band was recently created by the FCC to provide additional channels, using advanced technology to increase the number of channels available. In particular, this band is channelized into 5-kHz wide channels (compared with the typical 15-30 kHz channels in other bands). To squeeze a voice channel into 5 kHz requires the use of digital compression techniques or amplitude companded single-sideband (ACSB) technology. ACSB receivers are quite complex and must be perfectly adjusted to work well. Fortunately, receivers making extensive use of ACSB principles implemented with digital signal processing (DSP) chips are appearing in the market; they should offer major improvements over traditional ACSB construction. Notwithstanding the new DSP techniques, ACSB is likely to be expensive. It will probably not be extensively used in rural areas, where the availability of frequencies in other bands makes ACSB techniques unnecessary.

The 470-512 MHz band includes UHF TV channels 14-20, some of which have been selectively converted to LMR bands in the largest major metropolitan areas. Since these bands are used for LMR only as needed to relieve extreme LMR crowding, they are not available in rural areas.

The paired bands at 806-821 MHz and 851-866 MHz are designed to allow commercial, 25-kHz bandwidth, trunked SMR, as well as conventional land mobile radio operation. The adjacent 821-824 MHz and 867-870 MHz bands are reserved for exclusive public safety (e.g., State Highway Patrol) operation. The paired bands at 896-901 MHz and 935-940 MHz are divided into 12.5-kHz channels. These bands can be used for multichannel trunked systems, and half the channels are allotted exclusively to SMR systems. Presently, most SMR licenses are in the 800- and 900-MHz bands. Since the cellular telephone bands lie adjacent to these bands, it is relatively easy to adapt some of the intensively-competitive cellular developments for use in these bands. Expect to find some particularly small handheld radios in this band. Because of the relatively high frequencies, the operating range of this band will be relatively small.

4.2 HF Radio

High frequency (HF) radio is one of the oldest forms of long-distance wireless communication, and is a rich and ongoing field of research. Many volumes have been written on this subject; several recent treatments are those by Davies (1989), Goodman (1992), and Maslin (1987).

Propagation of radio waves in the HF band of the spectrum, defined as 3-30 MHz, occurs in two primary modes: the ground wave, in which radio wave energy remains near the surface of the Earth, and the sky wave, in which radio waves are reflected from ionized layers in the Earth's upper atmosphere (ionosphere).

The ground wave can typically be used for communicating over distances up to 60 miles, depending on terrain conditions (conductivity) and transmitter power. Ranges up to 100 miles can sometimes be achieved at transmission frequencies below 4 MHz, but as the frequency is increased, the radio waves experience increased attenuation. Ground wave propagation is relatively simple, in that the received signal can be viewed as a delayed and attenuated, but otherwise undistorted, replica of the transmitted signal.

At longer ranges (typically greater than 90 miles), HF communication depends upon sky wave propagation. Unlike the ground wave, the sky wave returns are highly variable and dependent upon frequency, time of day, season, solar activity, and geographic location. In addition to this variability, sky wave signals also suffer a number of impairments, including the interruption of communications by ionospheric storms, a large number of possible propagation paths resulting in time dispersion of a signal, high levels of interference, large and rapid fades, and frequency dispersion of wideband signals.

For these reasons, the effective use of HF equipment traditionally required experienced operators who could avoid poor-quality channels by identifying the optimum frequency for a given time and geographic location. It was also the responsibility of the operator to avoid interference with traffic already in progress and to monitor other appropriate channels.

Despite these shortcomings, HF has remained the communications medium of choice for many applications, because a low transmit power can often provide extremely long range communications (without the need for repeaters or the use of satellites) when the proper transmission frequency is used. Moreover, progress in HF technology since the 1970's has reduced the need for skilled operators. Modern HF equipment incorporates a high degree of automation as a result of developments in automatic tuning and antenna matching systems, remotely controllable systems, and automatic link establishment systems. In addition, hardware developments such as solid-state circuits, highly stable oscillators, frequency-agile synthesizers, fast tuning antenna couplers, and solid-state power amplifiers have improved HF communications considerably. The advent of very large scale integration has led to smaller, lighter, more power efficient, and more reliable equipment.

HF equipment is low in cost and has a long operating life. HF transceivers cost on the order of $1,000, and HF modems typically cost between $200 and $1,000. Expected life cycles of the equipment may exceed 10 years. HF antennas are rapidly deployable and do not need the accurate siting required for line-of-sight transmission. Antennas can be either omnidirectional or directional, and can be wideband or narrowband, depending on the application.

The recent advances in HF technology, the low cost and durability of HF equipment, and the large area coverage of HF skywave propagation suggest that HF radio may be appropriate for some user services in rural areas. Typical bandwidths for civilian uses of HF radio are on the order of several kHz; data transmission rates are generally not more than 1200 bps. Thus, HF radio cannot be expected to support applications involving video, but can meet the bandwidth requirements for voice, data, and fax services including electronic commerce and computer networking applications.

Although not currently in widespread use, HF technology presently exists that would enable a remote rural user to access public information. An example architecture that could be used for this application is shown in Figure 4-3. A remote user equipped with a computer, an HF modem, and an HF transceiver can communicate via HF with a gateway that has Internet access or a public bulletin board system. The gateway consists of an HF transceiver, modem, computer, and appropriate interfaces.

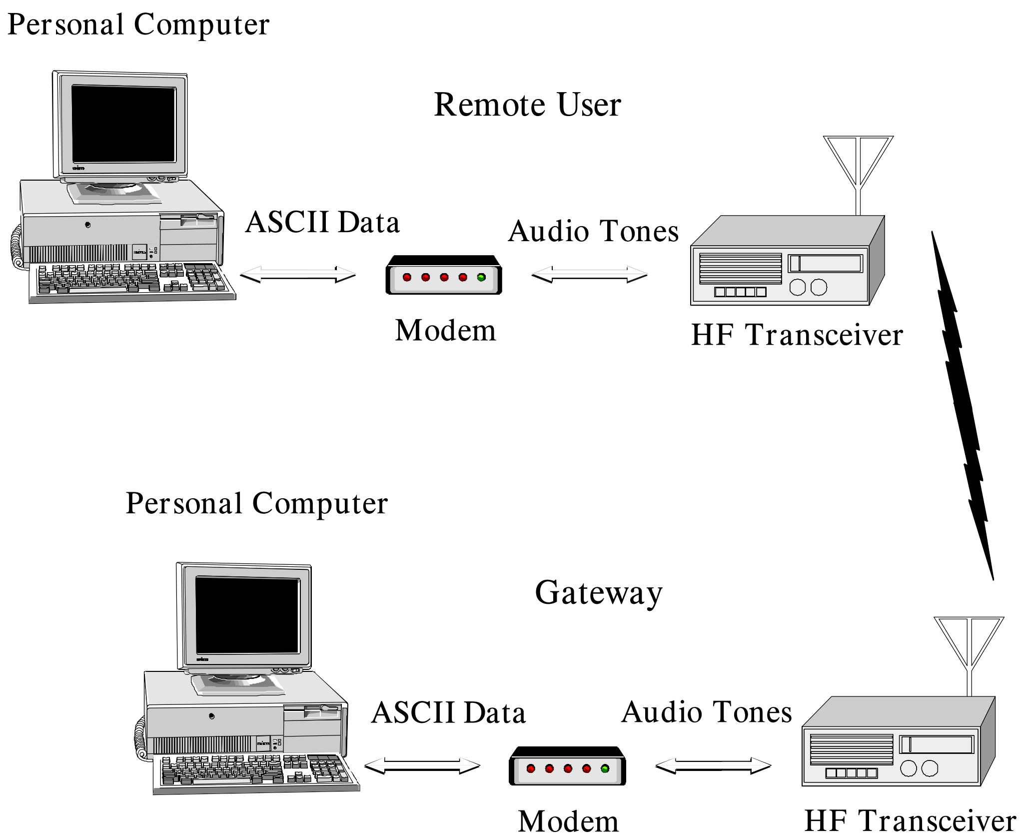

Figure 4-3. Remote user access to public information via HF radio.

While HF radio can provide access to the Internet or public bulletin boards, it can only provide limited services due to the relatively narrow bandwidth that it can support.

4.3 Terrestrial Broadcasting

The terrestrial broadcast of radio and television programming has played a dominant role in information and entertainment delivery to rural communities. These communities rely on broadcasters for public weather advisories and predictions, economic information, as well as public safety and service announcements. These services have been provided using technology that was developed decades ago. With broadcast radio, the technology is over a century old. The longevity of these technologies is due to the fact that they are based on standardized, reliable, and relatively inexpensive receivers. The transmission standard is an analog one, in which the information (voice and video) is encoded as a continuously variable parameter. While this technology is proficient at distributing analog signals such as voice and video, it does not allow digital data to be transmitted easily.

Several technologies are currently poised to deliver high quality voice and video as well as data services using conventional terrestrial broadcast frequency allocations available to rural populations. These include the development of high-definition television (HDTV), digital audio broadcast (DAB), and FM high-speed subcarrier (FM HSS) services. Each of these technologies approaches the problem of information delivery from a different perspective and offers various levels of enhanced service. They each have certain drawbacks to their use in exchange for their enhancements.

In a rural setting, there is no one dominant type of terrestrial service that is universally available. The accessibility of television and radio broadcasts varies substantially in different parts of the country. Therefore, there is no one service that can accommodate the needs of every rural community.

4.3.1 Broadcast Television

Analog television in the United States was put into operation in 1946. By 1949, receiver sales were exceeding 10,000 per month. There are approximately 160 million television receivers in the United States today (Netravali and Lipman, 1995). The current U.S. standard, called NTSC, breaks the transmission up into three separate subtransmissions: the picture (luminance), the color information (chrominance), and the audio. The picture transmission is based on transmitting moving pictures as a sequence of individual still pictures called frames. The system transmits 30 frames per second, and each frame has the equivalent of 480 x 440 individual picture elements, or pixels. The number of pixels, 480 x 440 in this case, is called the resolution. Each frame is drawn to the screen as a succession of horizontal lines. The process of drawing lines on the screen is called scanning. Since the human eye can distinguish a noticeable flicker from the scanning at the 30 frames per second frame rate, the pictures are drawn to the screen in two separate passes. Each pass draws half of the picture to the screen. Using this method, called interlacing, the screen is actually updated 60 times per second, which suppresses the perceived flicker. Several enhancements have been added to this basic system, including stereo encoding for the audio, additional audio programming channels, very low data rate digital transfer (closed captioning), and ghost canceling. These are minor enhancements compared to the technological improvements represented by HDTV.

HDTV is the term used to describe a proposed video and audio delivery that departs from the NTSC standard to provide significantly higher resolution audio and video, as well as data services. The current system proposed for the United States will offer several display resolutions (up to 1920 x 1080 pixels) and 5-channel compact disk (CD) quality surround sound (Grand Alliance, 1994).

After a period of competition between proponents of various systems, several organizations joined together and formed a consortium called the Grand Alliance. These organizations combined the best aspects of their individual systems and produced the Grand Alliance HDTV System. The Grand Alliance HDTV System is a transmission standard for digital television. It does not include any video production, display, or consumer equipment interface standards. The system does specify that the video and audio are to be digitized, compressed, and transmitted in a data stream according to the Motion Pictures Experts Group (MPEG-2) format. The data is to be broadcast using an 8-level vestigial sideband (8VSB) modulation.

The specifications for the Grand Alliance HDTV System call for a flexible data packet structure that can deliver many services to the receiver. Besides the video and audio packets, ancillary data packets are included in the specifications that allow the broadcast of any arbitrary data stream. The broadcast permits one-way data transmission only. Systems that require interactive communication need to provide an alternative means of communication back to the service provider. The packets can also be addressed to a specific receiver or group of receivers, allowing the data to be decoded only by those receivers that request it. Using the ancillary data service, some examples of services a broadcaster could provide include: programming information, software delivery, video or audio delivery (like pay-per-view programming), and instructional materials.

The ability to send high resolution video and audio in the same 6-MHz allocation used by conventional NTSC television relies on advanced digital compression technology. The compression algorithms produce a data flow that is dynamic in its data rate requirements. That is, when the program can be heavily compressed, such as a slowly changing scene or still, the data throughput required is low for the video. When the program contains rapidly changing scenes, the required data rate is higher. As a result, the entire 19-Mbps rate provided by the transmission system is not required for the video and audio at all times. There is room for other types of services to be broadcast, which may not be related to the primary video program. Figure 4-4 shows a diagram of the data structure for transmission of HDTV programming, including an ancillary data packet.

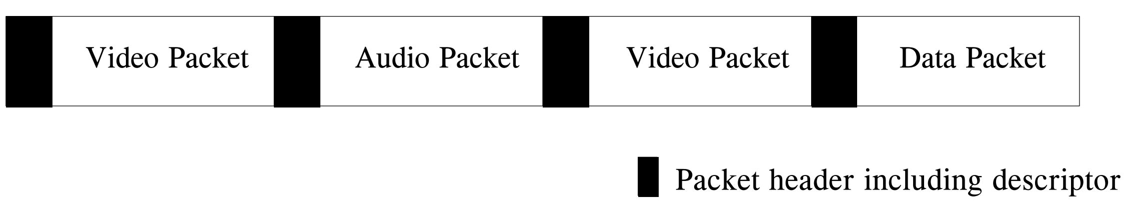

Figure 4-4. Data structure for transmission of HDTV programming.

The data rate available for ancillary service is dynamic and ranges from a few kbps to many Mbps, depending on the video and audio program content. Transmission of the ancillary data has a lower priority than transmission of the primary program, and must wait for an opening in the data stream for transmission.

The Grand Alliance HDTV System is currently being tested at the Advanced Television Test Center in Charlotte, North Carolina. Recent field tests have shown that the coverage is better than conventional NTSC television broadcasts (Association for Maximum Service Television, Inc. et al., 1994). Upon completion of testing, the Grand Alliance HDTV System will be presented to the FCC for approval. Currently, there is no HDTV coverage in the United States. The FCC plans to introduce HDTV initially by allowing broadcasters to offer a simulcast of their regular programming, transmitted on UHF television assignments. The period of simulcast will continue for up to 15 years as NTSC broadcast facilities and receivers are phased out. Receivers for the HDTV system will also include the capability to receive and display regular NTSC broadcasts. The receivers are expected to cost around $5000 initially with the goal of $1000 after several years.

Data broadcast is particularly suited to rural areas. Covering large areas, as typically required in rural areas, can be achieved by using higher transmitter power and/or higher antenna gain at either the transmitter or receiver rather than requiring additional wireline transmission media. Data broadcast using HDTV, however, does require a large capital investment from the service provider, and a substantial purchase by the user.

4.3.2 Broadcast Radio

Two separate technologies are being tested to bring digital audio and data services to conventional radio broadcasts. The first, FM HSS, incorporates digital data into the conventional FM broadcast by adding the digital data signal to the existing audio signal before FM modulation. Figure 4-5 shows this operation. The second, DAB, is a fully digital transmission that is transmitted in addition to the conventional FM. This separate signal is added to the conventional FM signal after the FM modulation, as shown in Figure 4-5. Unlike HDTV, these systems do not replace the analog service, they provide additional services and are completely compatible with conventional AM or FM broadcasts. The additional services are available only to those users with a receiver capable of accessing the digital data.

FM subcarriers have been used for many years in FM broadcast. In a conventional FM broadcast signal, the stereo sound does not require the full channel bandwidth that is allocated. The additional bandwidth available may be used to broadcast additional services by adding signals to the existing audio signal before FM modulation (as in FM HSS). These additional services currently include the Radio Broadcast Data System (RBDS), a very low bit rate data stream used to identify stations by call letters and to provide information about program content; paging services; and low bandwidth audio broadcasts including Muzak®, and others. While some of these services do provide a very low bit rate digital service, prototypes for a new high-speed data service (FM HSS) have been developed by several proponents. This new high-speed data service is incorporated into the FM signal in the same way a conventional subcarrier is added. The difference between conventional subcarriers and the high-speed subcarrier systems is the data rate of the service. Current conventional subcarrier systems provide, at most, a few hundred bps of data to a receiver. Current prototypes of FM HSS systems provide data rates up to 8 kbps; other systems are planned that will provide data rates up to 56 kbps (Small, 1994).

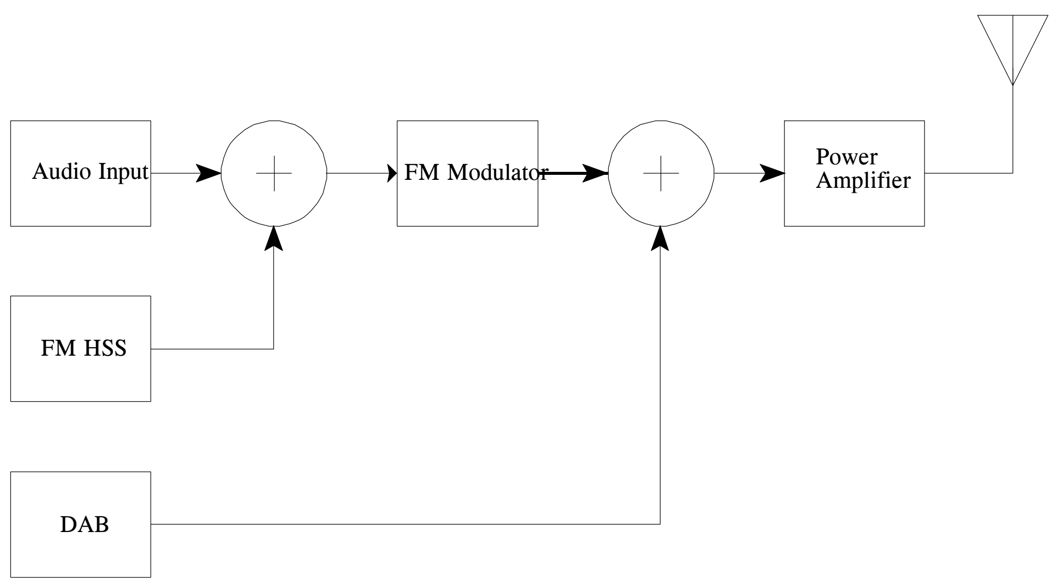

Figure 4-5. Insertion of FM HSS and DAB into a conventional FM broadcast.

The current FM HSS systems are designed to provide data services to mobile users. The primary interest is in providing mapping services and traffic information to automobiles as part of Intelligent Transportation Systems. The FM HSS systems are not designed to provide this type of service exclusively, however. The system architecture allows any type of data service to be provided. As in the HDTV system, the data can be addressed to a specific user or group of users with compatible receivers. FM HSS technology has advantages over HDTV technology; it is much more mature and is currently available for broadcast. Since FM subcarrier systems are typically installed and administered by a company that is separate from the broadcaster; there are no equipment costs required by the broadcast station to include this service. In fact, it generates revenues for the broadcaster in the form of fees paid by the subcarrier service provider.

A separate digital system, DAB, is being proposed for use in the United States to broadcast digital CD quality audio to properly equipped receivers. DAB is broadcast on the same allocated frequencies as conventional FM. Unlike HDTV, DAB can coexist with the conventional signal because the conventional FM broadcast signal does not use its entire allocated channel bandwidth. Figure 4-6 shows how the DAB signal exists outside the conventional FM broadcast signal, but is still within the channel allocation of the conventional FM signal. As in HDTV, compression is used to transmit the audio program, allowing for a dynamic data delivery capability.

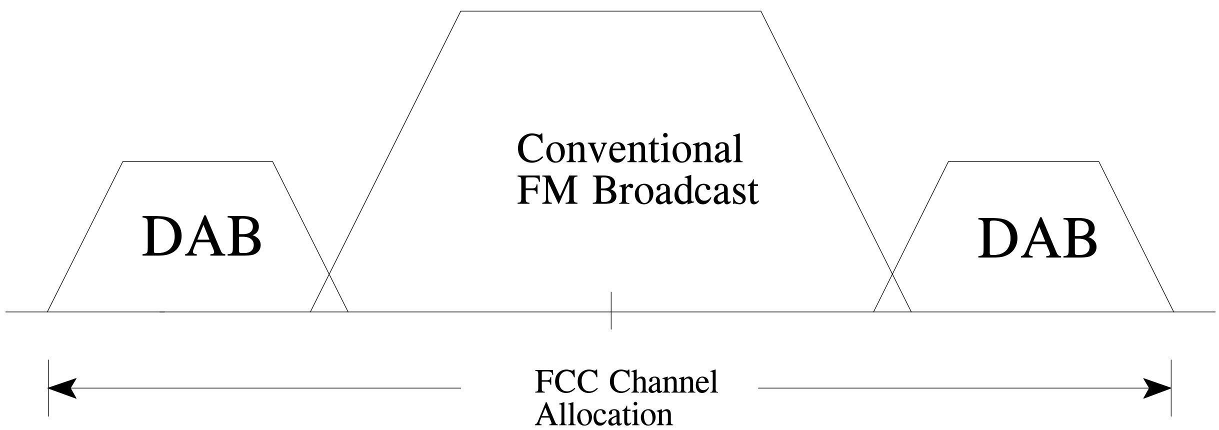

Figure 4-6. Frequency spectrum for conventional FM broadcast and DAB.

A series of field tests conducted by the National Radio Systems Committee was recently completed on several prototype DAB systems. The results of these tests will determine the system to be recommended for use in the United States. The types of service, scaleability, coverage area, and receiver costs are nearly the same for DAB as for FM HSS systems. DAB has a greater data rate available for audio services, but the ancillary data rate available for non audio services is dynamic, as in HDTV systems. The ancillary data rate available is based on the current level of compression in the primary programming. As with HDTV, both DAB and FM HSS systems provide one-way transmission only. A separate communication path from the user to the service provider is required for interactive services.

The entry of digital transmission into commercial broadcasting represents a revolution in the types of services that will be available to the public in the near future. HDTV, DAB, and FM HSS all share a significant advantage for rural users in that they do not require the installation of new transmission media, such as cable or fiber. This advantage comes with a price in terms of high receiver costs, lower data rates, and the lack of interactive communication (communication from the user to the service provider requires a separate technology).

4.4 Multichannel Multipoint Distribution Service (MMDS)

MMDS is more commonly known by the oxymoron "wireless cable." MMDS is a radio alternative to cable TV distribution. It may be particularly important in rural areas because it can be used to distribute up to 33 TV channels in some situations where there is neither local broadcasting nor sufficient customer density to support a regular cable system. In this context, it is primarily an alternative to satellite TV, with the additional advantage that MMDS can supply local channels.

MMDS provides up to 31 channels (each 6-MHz wide) of NTSC television over the frequency range from 2500-2690 MHz. Two additional channels can be broadcast in the 2150-2162 MHz range. Finally, there are 31 "response channels" available near the upper end of the 2500-2690 band, each channel having a 125-kHz bandwidth. These channels were originally intended to transmit a voice channel from a classroom to a remote instructor. They were provided so that the TV channels could be used to provide TV instruction to a remote classroom (Instructional Television Fixed Service; ITFS). ITFS has been used in rural areas, and a given channel is sometimes shared between ITFS (during the school day or work day) and MMDS (after hours and on weekends). In addition to using ITFS channels, MMDS can use channels licensed for the multipoint distribution service (MDS), a precursor to MMDS, and the Operational Fixed Service (OFS), a private point-to-point microwave communication service. Figure 4-7 shows the frequency allocations for these services, including MMDS, MDS, ITFS, OFS, and the response channels.

MMDS is allowed to radiate up to 100 watts per channel using an omnidirectional antenna. The receivers, usually at a home, use a high-gain directional dish antenna (about 30" in diameter) and a down-converter (that usually converts the selected channel to ordinary VHF TV channel 2 or 3). The range of the service is generally limited to line-of-sight operation however, the line-of-sight can be 10-20 miles if the terrain is favorable. The receiver requires only a simple frequency conversion, since the TV signal is already broadcast in the proper NTSC format, suitable for viewing on an unmodified TV set. However, the down-converter must also provide for the necessary decoding and access to prevent pirate viewing.

Typical costs of MMDS for the rural homeowner include a $30 monthly fee for antenna and down-converter rental and program subscription costs. It is claimed that an MMDS system operating in a rural environment can earn a profit with only 800 subscribers (about 10% of the total number of subscribers required for profitable operation of a normal cable system).

Although MMDS is a relatively old service, FCC rule changes in 1990 allowed single operators to license larger numbers of channels and operate them as a system, which made MMDS more economically viable. A tidal wave of industry interest resulted in 24,000 license applications. As of July 1994, about 160 MMDS systems were operating or expected to be operating before the end of the year, with half of them serving rural areas. Figure 4-8 shows the geographic distribution of MMDS licenses in the United States in October 1994. The size of the circular dots represents the number of MMDS licenses in each 1-degree (longitude) by 1-degree (latitude) area. (While the dots are positioned at the center of the 1-degree by 1-degree area, this does not imply that the respective MMDS systems are actually located in the center of this area.) MMDS licenses are widely distributed in rural areas, unlike in urban areas where the licenses are more densely concentrated.

There is typically only one MMDS system in a geographic area, since current economics seem to suggest that a minimum of 20-25 frequency channels are required by each MMDS operator. Thus, although a total of 33 channels might be available in an area, this is not quite enough to

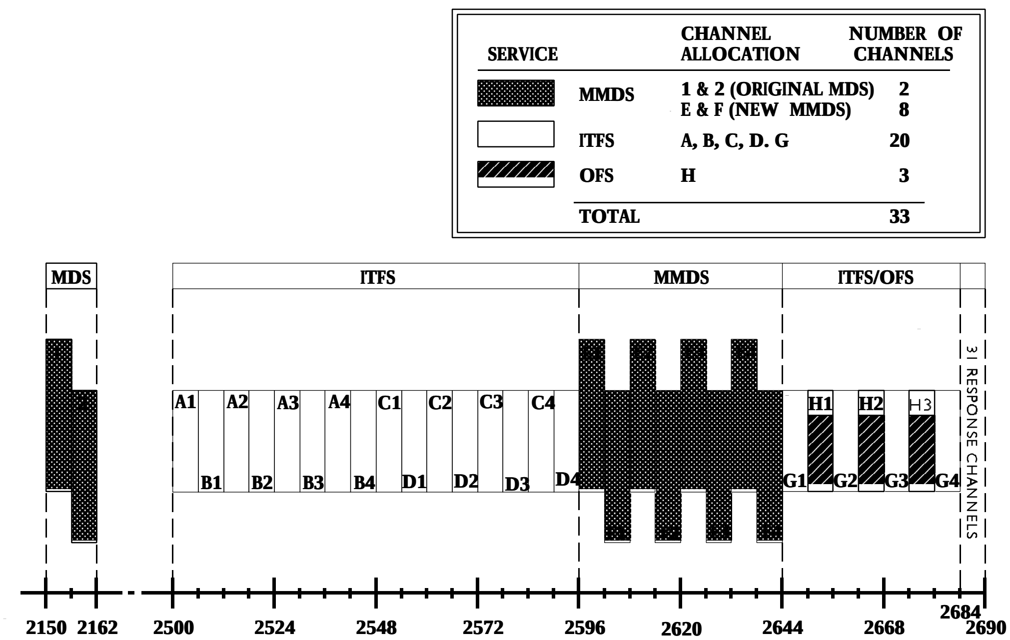

Figure 4-7. Arrangement of MMDS, MDS, ITFS, OFS, and response channels in the Radio Spectrum.

support more than one MMDS operator (especially since some channels may already be in use by ITFS or OFS operations). This would probably not be a major issue in rural areas, where the major question is whether there is enough customer demand to support even one MMDS operator. It is not yet known how the increased number of channels made available by digital compression techniques will affect the economics of minimum size configurations.

Figure 4-9 shows the geographical distribution of licenses for the ITFS that shares the 2500-2690 band with MMDS. These channels are used to bring video classroom instruction to factories or

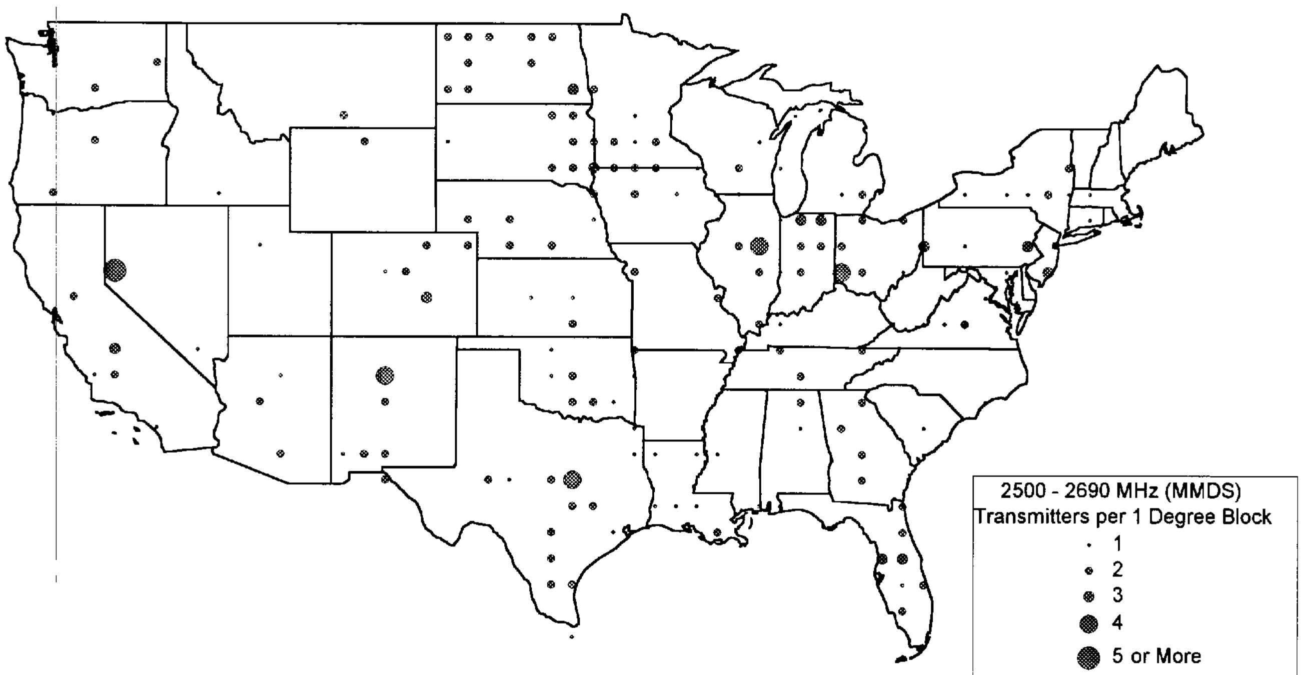

Figure 4-8. Geographic distribution of MMDS licenses in the United States.

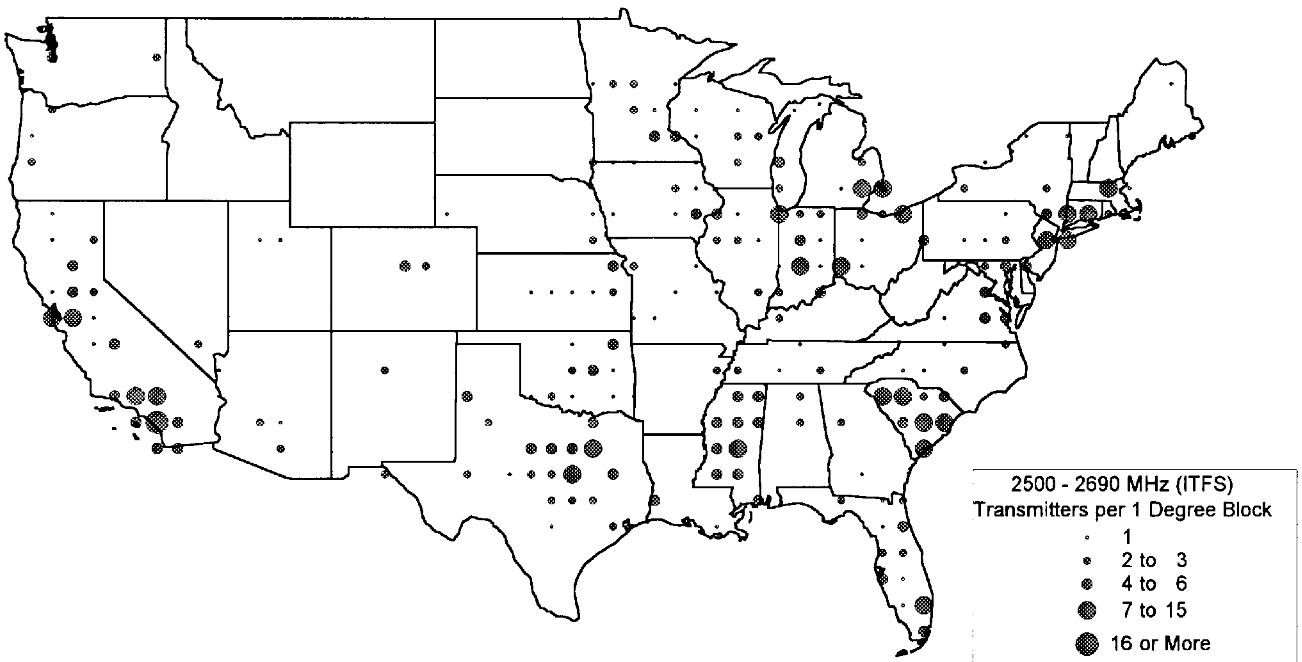

Figure 4-9. Geographic distribution of ITFS licenses in the United States.

to other remote classroom locations. The striking difference in the concentration of these licenses between several states shows that some state educational organizations have used ITFS extensively, while others have not. ITFS is a much older service than MMDS. It is possible that future educational video will be more widely distributed by optical fiber networks than by ITFS. At present, ITFS is often used to enrich junior college classroom offerings and used for adult evening classes at remote locations.

Since MMDS systems will generally want to use the 20 ITFS channels for their MMDS system, and since the ITFS channels are often unused in many rural environments, an MMDS operation will often assist a local school system in obtaining the licenses for the ITFS channels. The school system's ITFS channels will then be shared with the MMDS operator. This sharing may be a simple matter of available access; the schools can use their channels via MMDS facilities whenever they want, but their channels are used for MMDS programming at all other times. This mutually beneficial arrangement provides the school with the use of MMDS facilities to receive selected satellite programming and transmit it to schools and homes. In most cases, however, neither the MMDS operator nor the school has the ability to produce original program material.

There can also be much more active MMDS involvement with the schools. For example, the MMDS operators and the high school TV mass media class in Ada, Oklahoma arranged to borrow a remote satellite TV truck. The students assisted in TV coverage of the local team's participation in the state football finals. Coverage of several games was transmitted by satellite to the local MMDS system and broadcast to the local community via MMDS.

Local multipoint distribution service (LMDS) may provide a similar service as MMDS at some future time. LMDS will probably be located near 30 or 40 GHz. LMDS might be considered a higher frequency version of MMDS. LMDS is expected to provide general two-way services, including voice, video, and data in a large city environment, in addition to TV. This suggests that the role of MMDS might also be extended at some future time to include general telecommunications.

As in the cable TV industry, the MMDS industry is experimenting with digital compression techniques. For example, one system being tested puts 10 TV channels on a single 6-MHz bandwidth. Other systems provide 4:1 compression. The prospect of MMDS with 200-300 video channels completely changes the economics of providing MMDS. In addition, return path channels are mostly unused. Some operators have proposed using the MDS channels (2150-2160 MHz) for return path channels. The use of return path channels could allow interactive video services such as home shopping and video on demand as well as general two-way telecommunications.

The future of MMDS is filled with optimistic uncertainty. Although many licenses were requested after the 1990 rule changes, relatively few systems were actually built. Currently, the number of new, rural, analog systems becoming operational is increasing rapidly, partly because the licensing process is moving more rapidly now. Some companies claim that payback on investment is reached within 18-24 months. The FCC has long recognized the commercial value of MMDS licenses and has recently said that most of the remaining MMDS licenses will be distributed by FCC auctions.

The huge expansion of capacity that digital compression allows has attracted another major round of industry interest. In addition, while it is clear that digital compression will increase opportunities for MMDS, it will also similarly increase opportunities for satellite TV and cable TV distribution. Therefore, MMDS may not necessarily flourish, but the potential is present.

4.5 Wireless Telephone Systems

This section describes the various types of radio systems designed primarily to provide a wireless connection to the public switched telephone network (PSTN). These systems can be either fixed, mobile, or portable for applications where service is provided to a building, a vehicle, or to a person (i.e., a handheld unit). The types of systems discussed include mobile telephone and the Improved Mobile Telephone Service (IMTS), cellular telephone, personal communications services (PCS), subscriber radio, and Basic Exchange Telecommunications Radio Service (BETRS). While other systems can provide wireless access to the PSTN, SMR for example, their primary purpose is not wireless access to the PSTN. Therefore, they are not covered in this section. Both subscriber radio and BETRS systems are primarily used for fixed applications while mobile telephone, IMTS, cellular telephone, and PCS are primarily designed for mobile or portable operation.

Advantages of wireless telephone access

As mentioned in Section 3.1, providing access to the PSTN via wireline in rural areas can be difficult and costly due to extremely long distances from the central office, difficult terrain, and unavailability of material for poles to run cables. One great advantage of wireless telephone access is that costs associated with access for a nearby subscriber (for example within a mile of the local switch) and for a far away subscriber (for example 20 miles from the local switch) are comparable (Calhoun, 1992, p. 92). Since distance is one of the primary obstacles in rural areas, wireless telephone access may provide some cost-effective solutions in these areas. The high costs of the local loop were discussed in Section 3.1. Since the cost of providing copper local loop is so high (average cost up to $1800 per loop), especially in the rural areas (costs of $3000-$6000 per loop are not uncommon), wireless local loop can be a desirable alternative.

Cost of providing wireless telephone service in rural areas

There are two basic ways of examining costs for wireless telephone service in rural areas: the cost to the service provider for providing the service and the cost to the service subscriber to use the service. Costs to the service provider include the cost of the necessary equipment, equipment transport, shelter for the equipment, land, AC power, and installation, as well as operation and maintenance. Costs to the service subscriber can include equipment, installation, and AC power costs; user service fees; and maintenance costs. Furthermore, costs to the subscriber for using the service are dependent on many factors including cost to the service provider for providing the service, regulatory issues, and service provider policies (Westerveld and Prasad, 1994). All these costs, of course, are highly dependent on the type of system to be installed, the number of subscribers to be served, the amount of subscriber clustering, and the location of the particular service area. Because of these factors, it is difficult to generalize about the costs of providing service to subscribers for wireless access to the PSTN.

A common method of discussing the cost to the service provider (for providing a given service) is to use the average cost per subscriber. Calhoun (1992, p. 547) estimated that costs for wireless access were about $2000 to $4000 per subscriber for a "full telephony type application." This includes costs to fully equip and install a system but does not include operating and maintenance costs. This is sometimes called the "installed" cost or the "first" cost.

Traffic engineering

Throughout section 4.5, the number of subscribers served and the quality of that service for certain systems providing wireless access to the PSTN will be discussed. When considering wireless telephone access, the number of subscribers a system can provide service to is essential knowledge for a service provider. Additionally, any time service to a number of subscribers is contemplated, the quality of service to those providers must also be addressed. Quality of service, sometimes called grade of service, can be expressed as the probability of blocking. The probability of blocking in a wireless telephone system is the probability that a user will not be able to access the network (in one attempt) to make a call. The probability of blocking is given assuming a certain traffic intensity or traffic flow. Traffic intensity is the average number of calls made in a given time period multiplied by the average duration of those calls. It is often expressed in units of hundreds of call seconds per hour (CCS), which is the number of call seconds in an hour divided by 100. A commonly used unit is the erlang which is equal to 36 CCS (Bellamy, 1991). By assuming a given amount of traffic intensity, a system designer can determine how many channels are required in a wireless access system to serve a certain number of subscribers at a certain grade of service. Traffic intensity is typically specified for the busiest hour of a typical day. Wireline grade of service in the United States is usually specified at a blocking probability of .01.

4.5.1 Mobile Telephone

Mobile telephone service is defined as the interconnection of mobile users to the wired public telephone network. Mobile telephone service first began in the United States in St. Louis, Missouri in 1946. By 1947, more than 25 cities in the United States had mobile telephone service available. The systems used FM and a single high-power transmitter for the base station in the center of a metropolitan area. Coverage was provided 50 miles or more from the transmitter. These initial systems used a human operator at the base station to manually connect the mobile user with the landline network. While automatic, direct-dial service began operating in 1948 in Richmond, Indiana, most systems were operated manually for many years.

In many large urban areas, demand for mobile telephone service was greater than the available capacity. The service was very poor since too many subscribers were loaded per channel. It was not uncommon to have 100 or more subscribers per channel. The probability of the mobile user being unable to connect to a landline circuit was very high, up to 0.65 (Calhoun, 1988). Mobile telephone systems required much more spectrum than was allocated to be able to provide better service in the large urban areas.

From a spectrum efficiency standpoint the use of FM for these systems required much more bandwidth than AM systems. The original FM mobile telephone system was very spectrally inefficient. One hundred twenty kHz of spectrum was required for a single voice circuit having 3 kHz of bandwidth. Improvements in FM receiver design narrowed the channel bandwidth requirements down to 25 kHz, thus greatly improving the system capacity by the mid 1960's.

Another technical development that greatly enhanced the system capacity of the mobile telephone system was trunking. In the early mobile telephone systems, trunking was not used. These systems consisted of a set of channels where a group of users would share a specific, fixed radio frequency (channel). The transmitters and receivers for each group of users were designed to operate on a fixed frequency. In a trunked system, all of the users can use any of the channels. Channels that are not currently being used are identified and an unused channel is made available to each user. The advantage of a trunked system is that many more users can be supported with the same grade of service. Trunking in the early mobile telephone systems was implemented manually. The user could select an available channel manually by switching from one channel to another and listening for an unused channel.

In the mid 1960's IMTS was implemented. This service included system features such as automatic trunking, direct dialing, and full-duplex operation (Calhoun, 1988, pp. 29-35). The automatic trunking used a technique called marked-idle where a tone was placed on one of the available channels. A mobile telephone could then automatically select the open frequency channel by finding this tone (O'Neill, 1985).

IMTS systems were available for use in both the 150-MHz and 450-MHz bands. Besides providing mobile service, there were some IMTS systems used for fixed service in rural areas. While there may still be some operational IMTS systems in the United States, these systems are not currently being produced. IMTS is an obsolete technology. It has been replaced with cellular systems for mobile applications of wireless access to the PSTN and BETRS systems for fixed wireless access to the PSTN.

Growth mechanisms for IMTS

IMTS systems were implemented with a relatively small start up cost. To cover a large area only one base station was needed. The service provider could start with a given number of radio channels to accommodate the requirements of the users. Growth (the ability to add more subscribers) was achieved by adding extra radio channels. Even one channel at a time could be added if desired. In this way growth was easily controlled, managed, and was a low-risk (Calhoun, 1988, pp. 74-75).

4.5.2 Cellular Telephone

Traditional methods of mobile telephone such as IMTS utilized a high-power transmitter with a tall transmit antenna to cover a large area (out to the horizon). This provided coverage of up to 40 or 50 miles in radius. This type of system was quite spectrally inefficient since frequencies could not be reused within the entire coverage area of the system. The cellular concept was to break up this large area into many smaller areas called "cells." Within each cell, a low-power transmitter was used to provide coverage only within that cell. The same frequencies could be reused in different cells within the original large area. Frequencies could not be reused in adjacent cells because of interference between mobiles operating at the same frequency in these adjacent cells. Several cells needed to be skipped before reusing the same frequency. A key concept in cellular technology was that the same frequency could be reused based on a certain ratio of distance between the cells to the radius of the cells. Therefore, with smaller cell sizes, the same frequency could be reused a shorter distance away! It was found that the same frequency could be reused at a distance of approximately four to six times the cell radius (Calhoun, 1988, pp. 39-45). In theory, by decreasing the cell size one could increase the capacity of the system. By breaking up large cells into smaller cells, called cell-splitting, ideally one could provide for system growth and accommodate new users without requiring additional frequency spectrum. However, the area to be covered must be broken into many small cells to begin to achieve a great advantage in capacity based on frequency reuse. In other words, many base stations are required. Since each base station is costly and the network costs increase with more base stations, cell-splitting is quite costly.

Cell boundaries

For planning and design purposes, hexagonally shaped cells are used to cover an area with no gaps of coverage between the cells. These theoretically shaped cells have well-defined boundaries. In reality, however, the service coverage in a cell has irregular borders and may contain holes or areas within the cell's borders that do not have coverage. Because the cell sites have irregular borders, some areas between cell sites may not be covered.

Structure of a cellular system

A cellular system consists of a mobile telephone switching office (MTSO), cell site base stations, and mobile units. Figure 4-10 shows this architecture. The MTSO is the central controller of the entire cellular system. It contains and controls the cellular switch that provides for connection between the mobile users and the PSTN. It also controls the call processing and takes care of

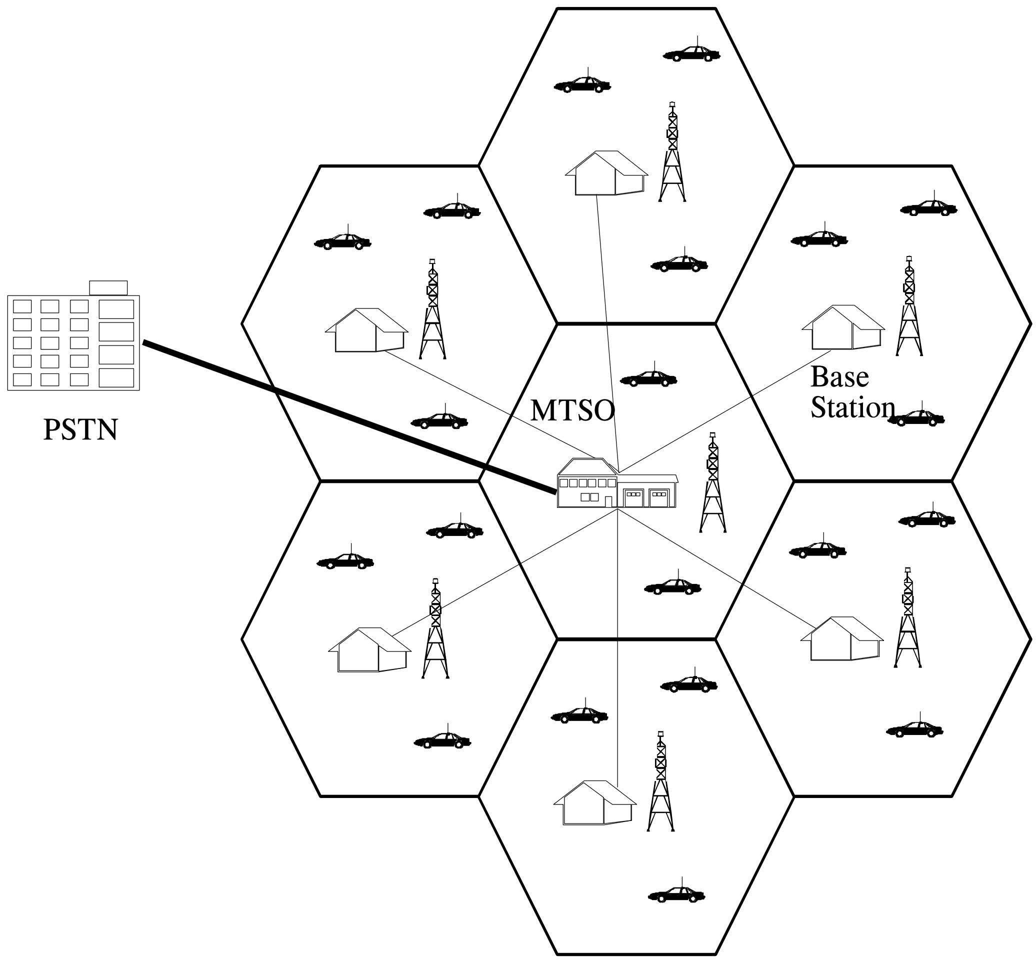

Figure 4-10. Cellular system architecture.

billing. The MTSO connects to the PSTN and to each cellular base station. These connections can be via wire or microwave radio links. Each cellular base station provides a radio link to the mobile subscribers that fall within the base station's coverage area (cell). Typical cell sizes for mobile cellular systems range from about 0.5 to 10 miles in radius (CTIA, 1994).

Growth mechanisms for cellular systems

In a cellular system, of course, to cover a large area, many base stations (one for each cell) must be constructed. In addition, these cell sites must be connected to the MTSO. Consequently, there is a very large initial investment in setting up a cellular system. While many more users can be supported with a cellular system compared to an IMTS system, a much greater risk is assumed because of the high initial cost and the necessity of recruiting a great number of users to make the system profitable while providing service at a reasonable cost. To achieve growth in a cellular system, more base stations must be added. This, as with the initial investment, is both costly and risky.

Grade of service

The initial goal of cellular service was to achieve a voice quality and blocking probability similar to wireline service. During the busiest hour the blocking probability of a cellular system was expected to be .02 or less. This is in contrast with that of the IMTS systems which was .50 or more.

Analog and digital cellular systems in the United States

While there are many different cellular systems throughout the world, only the systems that are most prevalent in the United States will be discussed here. All cellular systems in the United States, analog or digital, operate over the same allocated frequencies. The original analog cellular system in the United States, which is still in widespread use, is the Advanced Mobile Phone Service (AMPS). The AMPS system uses ordinary FM modulation and frequency-division multiple access (FDMA). In an FDMA system, the total frequency allocation is broken into individual frequency channels. Each of these channels provides for only one circuit path (either for voice or for a control signal). (A circuit path, otherwise known as a transmission path, is a means for transmission of a signal.) Because of this, FDMA systems are known as single channel per carrier systems. A user may access any of these channels that is not in use.

There are two primary types of digital cellular systems in the United States. The IS-54 standard is based upon time-division multiple access (TDMA) while the IS-95 standard is based on code-division multiple access (CDMA). In TDMA, each frequency channel is divided into individual time slots. Each of these time slots comprises a single circuit path that can be used as a voice channel or a control channel. The frequency channel is thereby shared by a given number of users (equal to the number of time slots). This sharing is accomplished by repetitively transmitting a frame consisting of all of the individual time slots. Each user transmits a burst of bits within a particular time slot during transmission of a frame. In the user's time slot of the next frame, the next burst of bits is transmitted. This process is then repeated for all frames. In the IS-54 standard, as well as in other systems, TDMA is used along with FDMA (i.e., the entire frequency allocation is divided up into narrowband channels and each of those channels consists of individual time slots). The IS-54 standard provides three circuit paths per frequency channel.

CDMA is the most conceptually difficult of the three multiple access schemes discussed here. In FDMA systems a separate frequency channel is used by each user, allowing transmission and reception without interference from other users. In TDMA systems, each user has his own time slot also permitting transmission and reception without interference from other users. In CDMA systems, many users transmit over the same (wideband) frequency channel at the same time. Transmission and reception for each user are accomplished by using a unique code for each user thus enabling traffic from one user to be distinguished from all of the others.

CDMA systems typically use one of two types of spread spectrum techniques: frequency hopping spread spectrum or direct sequence spread spectrum. In both techniques, each user is assigned a unique digital code called a pseudorandom noise (PN) code. In the frequency hopping technique, a wide band of frequencies is divided up into many narrowband channels. The PN code is used to make the transmitter “hop” from one of these channels to another at a rapid rate in a predetermined pseudorandom sequence. Each user transmits with a different PN code and therefore uses a different sequence of these channels. Reception of the desired user's transmission is accomplished by applying the same PN code sequence to tune the receiver to the proper sequence of frequencies to receive the transmitted signals from the desired user. The ideal goal of frequency hopping spread spectrum is that no more than one user will transmit on each channel at the same time. In practice, this ideal goal cannot be achieved. However, the number of times that more than one user transmits on the same channel at the same time can be minimized by appropriately selected PN codes. Because more than one user occasionally transmits on the same frequency channel at the same time, some interference between the transmissions does occur. As more users are introduced into the system, this interference increases since transmissions of more than one user occur more frequently on the same frequency channel at the same time. Herein lies an interesting difference between CDMA systems and both TDMA and FDMA systems. In FDMA systems when all frequency channels are occupied and in TDMA systems when all time slots are occupied, additional users trying to use the system are blocked. For a CDMA system, the maximum number of users in the system is dependent on the amount of interference and subsequent performance degradation that is tolerable. Blocking does not occur in a CDMA system in the traditional sense; the amount of interference and subsequent performance degradation increases gradually as more users are added to the system (Calhoun, 1988, pp. 339-357).

A direct sequence spread spectrum transmission can be generated in different ways. One method is to first modulate a carrier with the desired data stream and then modulate this signal with the PN code sequence. Another method, and one that is commonly used, is called bit-inversion modulation. In this method the PN code sequence is modified by the desired data stream and then this modified PN code is used to modulate a carrier. Since the PN code is used to spread the energy in the data stream out in frequency (i.e., greatly increase the signal bandwidth) it runs at a faster rate than the desired data stream. The individual bits of the PN code, called chips, that occur during the time period of an information bit in the desired data stream, are unaltered if the information bit is a zero. If the information bit is a one, however, the chips that occur during this time period are inverted. At the receiver, the desired data stream is detected by correlating the received signal with a copy of the correct PN code sequence. In general, the correlation process determines the degree to which two signals are alike. When the transmitted signal that consists of the PN code sequence (modified by the desired data stream using bit-inversion modulation) is correlated with a copy of the unmodified PN code sequence, the desired data stream results. Undesired signals, including transmissions from other users in a CDMA system using direct sequence spread spectrum who are using other PN codes, produce a noise output at the receiver. This noise acts as an interference to the reception of the desired data stream (Hale, 1989). As in systems employing frequency hopping, the amount of interference and subsequent performance degradation in systems employing direct sequence spread spectrum, increases gradually as more users are added to the system (Calhoun, 1988, p. 355).

Cellular frequency allocations in the United States

Cellular service in the United States has frequencies allocated in two different blocks for each defined service area. Service areas for licensing of cellular operation were defined by the FCC based on modifications of definitions by the Office of Management and Budget (OMB). These service areas consist of 306 Metropolitan Statistical Areas (MSAs) and 482 Rural Service Areas (RSAs; Code of Federal Regulations, 1992). There are some rural areas within some MSAs and some RSAs are more "rural" than others. Each of the two different frequency blocks has 416 channel pairs available (21 of these channel pairs are reserved as control channels) with a 30-kHz spacing. Block A and B frequencies were reserved in the initial licensing by the FCC for non wireline and wireline carriers, respectively. In addition, transmit frequencies for the mobile-to-base station and for the base station-to-mobile are separated by 45 MHz. The frequency allocations for cellular service in the United States are summarized in Table 4-1.

Table 4-1. Frequency Allocations for Cellular Service in the United States

Frequency Block	Mobile-to-Base Station	Base Station-to-Mobile
Block A	824.04 - 834.99 MHz	869.04 - 879.99 MHz
	845.01 - 846.48 MHz	890.01 - 891.48 MHz
Block B	835.02 - 844.98 MHz	880.02 - 889.98 MHz
	846.51 - 848.97 MHz	891.51 - 893.97 MHz

Handoff

The cellular concept of a number of cells covering an area poses a problem. As one travels from one cell to another, the system needs to switch a call from the base station in one cell to the base station in another cell. This method of switching a call is known as handoff.

There are two fundamental types of handoff. One type of handoff is based on signal strength while the other type of handoff is based on the carrier-to-interference ratio. The signal strength-handoff occurs if the received signal level falls below a specific threshold. Likewise, the carrier-to-interference-handoff occurs if the carrier-to-interference ratio falls below a given level.

In general, handoff is a very important issue in mobile cellular systems and many different schemes are used. The type of handoff scheme used is influenced by whether the cellular system is an FDMA, TDMA, or CDMA system. Some manifestations of improper handoff result in dropped calls and crosstalk. Another potential problem is when a mobile is traveling in an area where coverage is on the borderline between cells. In this case, it is possible that the mobile will go through repeated handoffs thus increasing the processing load on the system (Calhoun, 1988, pp. 98-103).

In rural areas, handoff is not usually an important issue. This is because cellular systems in rural areas use much larger cell sizes (than in urban areas) and may only use one cell site for an entire service area.

Power control

In many types of radio systems and in particular in cellular systems, operating with the minimum amount of transmitter power to allow for reliable operation is desired. In cellular systems, the primary reason for this is to minimize interference (both co-channel and adjacent-channel) to other cellular users as well as to other radio systems. Cellular systems have the capability of adjusting the transmitter power of both the base station and mobile transmitters. The MTSO can monitor the performance of the whole cellular system and adjust the transmitter power to optimize the performance of the entire system (Lee, 1995).

Cellular systems in urban and rural areas

While cellular systems were initially designed to provide wireless access to the PSTN for mobile users, they are also quite suitable for providing this service to fixed users as an alternative to wireline access. There are two types of fixed cellular operation. In the first type of operation the cellular system is designed for mobile users. The system can be easily used by fixed subscribers within the cellular coverage area since fixed subscribers typically have less stringent propagation constraints than mobile subscribers. The second type of fixed cellular operation is when the cellular system is designed specifically for fixed subscribers, not mobile subscribers. This type of fixed cellular operation is what will be discussed here.

Fixed cellular applications are being proposed in various countries around the world in both urban and rural areas as an alternative to wireline service. Fixed cellular applications in developed countries are typically in rural areas. In developing countries, fixed cellular systems are sometimes preferred for both urban and rural areas. In the United States, since most urban areas have a well-established wireline network, cellular systems are not really used for fixed operation but are in wide use for mobile communications. However, there is good potential for the use of cellular systems for fixed applications in rural areas in the United States. Fixed cellular systems offer some advantages over mobile cellular systems including:

1) A simplified system design because handoff is not necessary.

2) The ability to use a tall antenna at the subscriber site thereby improving propagation.

3) The ability to use a directional antenna at the subscriber site to reduce interference and increase system capacity.

4) Less stringent signal-to-interference ratios are required since the fast multipath fading associated with mobile operation is not present.

Cell sizes for fixed cellular systems in rural areas can be up to approximately 35 miles in radius (Hashemi, 1992). The use of cellular systems for fixed applications in the United States represents one type of system that falls under the category of BETRS. This type of service will be discussed in more detail in a following section. Cellular systems are quite prevalent in the United States. Although data is not readily available on the number of subscribers that use cellular systems in fixed applications in the United States, the vast majority of subscribers use cellular systems in mobile applications. The average monthly bill for cellular service has dropped steadily since December 1987. As of December 1987, the average monthly bill was almost $97; as of December 1994, the average monthly bill was approximately $56 (CTIA, 1995). As of December 1994, CTIA (1995) estimated that there were almost 1600 cellular systems, almost 18,000 cell sites, and over 24 million cellular subscribers in the United States. In another estimate, MTA-EMCI, Inc. showed that as of December 1994 there were 24.5 million cellular subscribers in the United States with 2.5 million of those subscribers from RSAs. MTA-EMCI, Inc. also estimates that 10.8% of the total population in MSAs are cellular subscribers while only 4.5% of the total population in RSAs are cellular subscribers. Cellular service is available to about 96% of the U.S. population although the total geographic area coverage is much less, roughly 50% to 60% (Ross, 1995). A plot showing the geographic areas where cellular service is available in the United States is shown in Figure 4-11. Both the MSA and RSA boundaries are shown as thin black lines. The shaded regions represent areas where cellular service is available. Note that a large geographic area in Alaska is not covered and that this significantly influences the percentage of total geographic area covered in the United States. The plot shows that there are large areas in the western United States that are not covered; coverage in the eastern United States is more pervasive.

Cellular system user services

Cellular systems, like wireline telephone systems, were originally designed for two-way voice communication. Data communication is becoming much more prevalent on cellular systems. The specific way data is transmitted over cellular systems is dependent on the type of cellular system. Data rates up to 9.6 kbps can be reliably transmitted over an AMPS analog cellular channel using modems with cellular-enhanced protocols. Somewhat higher data rates can be achieved using compression techniques. Group 3 fax can be provided over an AMPS channel with fairly good reliability (Berg, 1995).

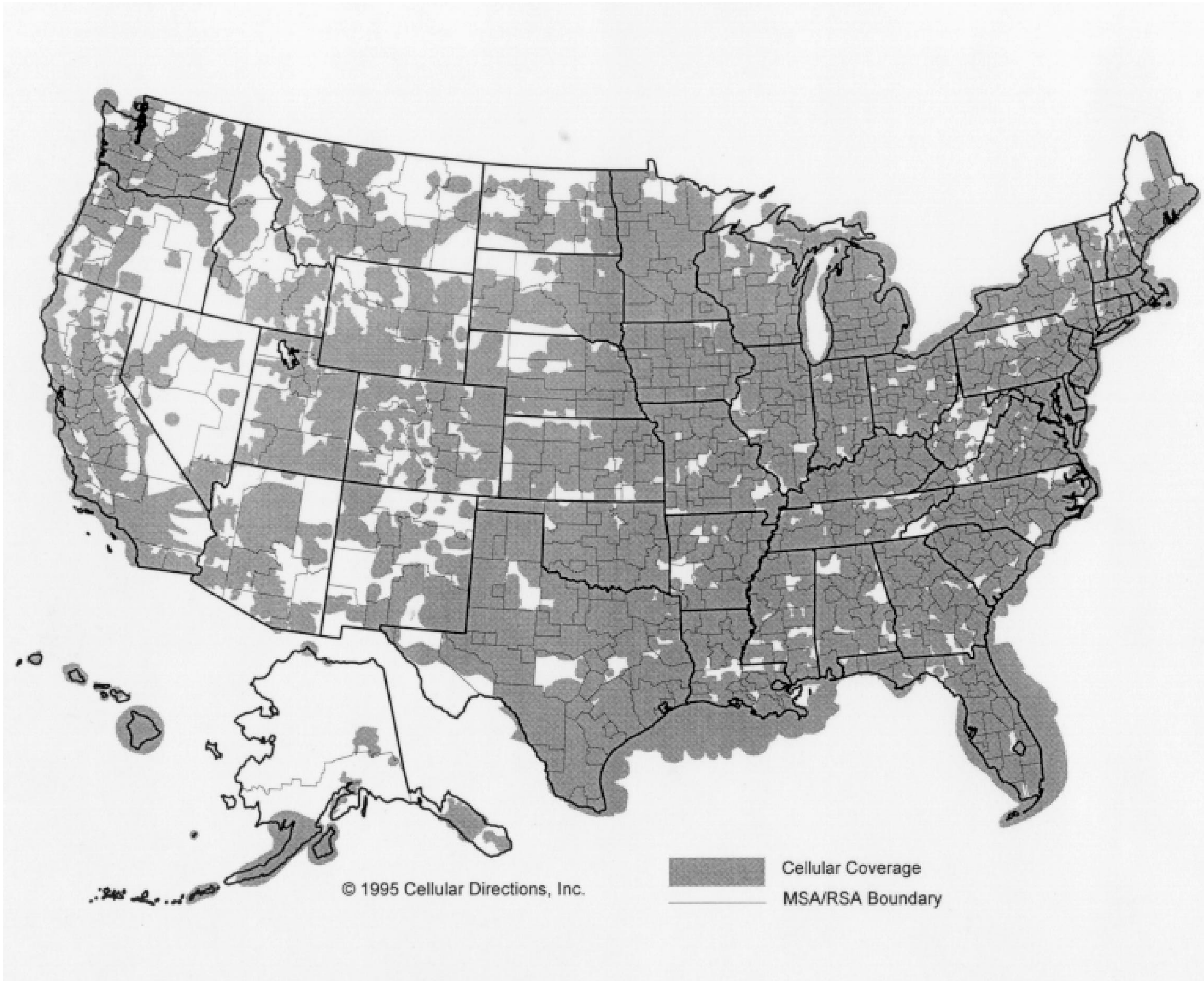

Figure 4-11. Cellular system coverage in the United States.

A relatively new technology, Cellular Digital Packet Data (CDPD), is available for data communication over AMPS channels. CDPD breaks data into packets and transmits these packets over the existing analog cellular network. While CDPD operates at a 19.2-kbps rate over each AMPS channel, the actual data throughput is around 12 or 13 kbps. CDPD can operate over a dedicated channel or can transmit packets over a voice channel during times of no voice transmission. For data communication using CDPD, the cellular carrier must provide the service and users must have a CDPD modem. Group 3 fax can be sent by transmitting a data file formatted for fax over the cellular network using CDPD to a server at the receive site. The server on the receive end then converts the packet data into a data file formatted for fax and sends this file to a fax machine. Typical costs for CDPD modems are around $400 while a typical cost for data transmission is about $0.12 per Kbyte.

Although TDMA and CDMA systems are digital, the initial standards for these systems have been written with voice service in mind. These standards have not yet included specifications for data operation. In the PCS section that follows, the limitations of data operation over digital systems designed primarily for voice communication will be discussed.

4.5.3 Personal Communications Services (PCS)

PCS comprises the services and technologies that are the second generation of digital mobile telephone service. These include both voice and data services coupled with the benefits of advanced network services. While PCS was originally envisioned as an advanced mobile telephone system based on a microcell architecture, market forces are driving it in the direction of a system similar to digital cellular but operating at higher frequencies. PCS does, however, offer paging and short messaging services among other services, not found in digital cellular.

PCS frequency allocation in the United States

The spectrum allocated for PCS in the United States, shown in Table 4-2, is divided into six licensed blocks and one unlicensed block. The unlicensed block is to be used for low power voice and data systems such as wireless private branch exchanges (PBXs). Blocks A and B are licensed within 51 service areas based on the Major Trading Areas (MTAs), and Blocks C, D, E, and F are licensed within 493 smaller service areas based on Basic Trading Areas (BTAs) set forth in the 1992 Rand McNally Commercial Atlas & Marketing Guide. The PCS rules (FCC Docket 90-314) specify that Block A, B, and C “licensees must provide coverage to one third of their service area population within five years and to two thirds within ten years” and that Block D, E, and F “licensees must provide coverage to 25 percent of their service area population within five years or submit a showing of equivalent or substantial service.” One intent of these “build-out” requirements is to ensure service to rural customers.

Technical standards for the PCS air interface are being developed in the Joint Technical Committee on Wireless Access (JTC). The JTC is a joint activity between Committee T1 and the Telecommunications Industry Association (TIA). Within the JTC, there are six air interface technologies being standardized for the licensed PCS blocks. A seventh standard may be added which will be based on the Digital European Cordless Telephone (DECT) standard. Four standards are being developed for the unlicensed band under TIA's TR41.6 technical subcommittee. Of the six technologies being developed for the licensed band, three are based on current digital cellular standards. This discussion of PCS will focus on the licensed block technologies.

Table 4-2. Frequency Allocations for PCS Service in the United States

Frequency Block	Mobile-to-Base Station	Base Station-to-Mobile
Block A	1850-1865 MHz	1930-1945 MHz
Block B	1870-1885 MHz	1950-1965 MHz
Block C	1895-1910 MHz	1975-1990 MHz
Block D	1865-1870 MHz	1945-1950 MHz
Block E	1885-1890 MHz	1965-1970 MHz
Block F	1890-1895 MHz	1970-1975 MHz
Unlicensed	1910-1930 MHz 2390-2400 MHz	

Proposed PCS technologies

The licensed block PCS technologies can be divided into two types of systems based on intended coverage. One, called a high-tier system, is targeted for large cell applications much like the existing cellular systems. The other, called a low-tier system, is targeted for microcell applications. The high-tier technologies tend to be robust against the impairment effects of radio transmission, such as multipath from reflections, scattering, and Doppler spreading created by motion of the mobile. However, high-tier technologies are commensurately more complex and provide lower quality voice and lower data rates. The low-tier technologies are more intolerant of multipath and are designed for operation at pedestrian speeds. However, low-tier technologies provide higher quality voice and higher data rates. Cell radii for the high-tier systems can range up to a few tens of miles while cell radii for the low-tier systems range only up to a few hundred yards.

All proposed PCS technologies are digital. In digital transmission of voice, the original analog voice signal is converted to a sequence of binary numbers (bits), encoded with error detection and correction bits, modulated, possibly spread in frequency, and then transmitted. At the receiver, the signal is despread if needed, demodulated, decoded, and then converted back into an analog voice signal.

PCS systems can provide data transmission services in addition to voice services. There are two primary ways to provide data transmission in a PCS system designed for voice transmission. In one case, the data stream bypasses the voice encoder and is injected directly into the digital system. This is the most appealing method since it provides the maximum data rate. The difficulty is that it requires specific modifications to the PCS system. There must be special equipment at both ends of the radio link to give access to the data stream, thereby adding to the cost of the service. The other approach is to use the more traditional voice-band modem and not bypass the voice encoder. A traditional voice-band modem modulates an audio frequency carrier with the data stream for transmission over a voice circuit. The frequency spectrum of the modem output falls within the required voice bandwidth.

In using the voice-band modem, the characteristics of the voice encoder are important. There are two basic methods of voice encoding used by PCS systems to convert the analog voice signal into a digital bit stream: waveform (or direct) encoding and predictive encoding. Waveform encoders tend to provide very high quality voice transmission, but require a higher bit rate. The higher bit rate reduces the spectrum efficiency of the system for voice circuits. Predictive encoders require a lower bit rate and are, therefore, more spectrally efficient, but provide poorer voice quality. Because of the higher data rate of the encoder, waveform encoders provide a greater voice bandwidth than do predictive encoders. Therefore, waveform encoders can support voice-band modems with higher data rates than predictive encoders. Data transmission, using a traditional voice-band modem, will result in a lower data rate than that achievable by bypassing the voice encoder.

Table 4-3 lists the six PCS technologies being standardized for the licensed PCS blocks and their associated system parameters. In this table, "Base Technology" indicates the name of the technology and whether it is a new technology or based on an existing cellular standard. "Access Method" indicates the multiple access method used, either TDMA, CDMA, or a hybrid of the two. "User Bit Rate Per Traffic Channel" is the same as the voice encoder bit rate without signaling or coding bits added.

PCS network architecture considerations for rural areas

As with the cellular telephone systems, PCS mobile network design is based on the cellular frequency reuse concept. In a mobile network, the system is either coverage-limited or interference-limited. Each base station has a certain number of radio channels available to it, and the provider would like to have as many revenue generating calls as possible at any given time. In the coverage-limited case, the subscriber density is low; therefore the cell is designed for maximum coverage. In the interference-limited case, the subscriber density is high. To provide the capacity needed, the cell size is reduced and the number of available radio channels is limited by interference from other nearby cells. Rural systems will likely be coverage-limited so the design would tend to maximize coverage area.

Table 4-3. Proposed PCS Technologies and Associated Parameters[1]

Base Technology	Omnipoint (new)	IS-95	PACS (new)	IS-54	GSM	W-CDMA (new)
Access Method	TDMA/ CDMA	DS-CDMA	TDMA	TDMA	TDMA	DS-CDMA
RF Band-width	5 MHz	1.25 MHz	300 kHz	30 kHz	200 kHz	5 MHz
User Bit Rate per Traffic Channel	8 kbps	Two rates available: 8 kbps or 13.3 kbps	32 kbps	7.95 kbps	13 kbps	32 kbps
System Type	High and Low Tier	High Tier	Low Tier	High Tier	High Tier	High and Low Tier
Voice Encoder	Predictive	Predictive	Waveform	Predictive	Predictive	Waveform
System capacity relative to AMPS	5x	10x	0.8x	3x	3x	16x

The traditional high-tier cellular-type network is intended to serve mobile subscribers from fixed base station sites. The base stations use an omnidirectional antenna where offered traffic density is low or they use a sectorized antenna when additional capacity is needed. Because of the wide area coverage and the motion of the subscriber, the radio link can be subject to severe multipath. To overcome this, equalizers, error correcting codes, and low rate voice encoders have to be used. This allows only lower rate data transmission. However, when the subscriber is fixed, such as in wireless local loop, the radio link can be engineered to reduce the multipath. In this case, a low-tier system can be used to allow a higher data rate. Data rates can also be increased by aggregating traffic channels. While not currently available, this capability is planned for future enhancements to some PCS technologies.

The optimal PCS design for rural areas might be a two-component design. A traditional high-tier system could be used to provide service to the mobile subscribers. Fixed subscribers could be serviced with a higher data rate low-tier system. For service to fixed subscribers, directional antennas, which reduce multipath, could be used at both ends of the radio link. A single high-gain antenna at the subscriber site and a multisectored high-gain antenna at the base station could be used. The data service could be provided either by bypassing the voice encoder or via a voice-band modem. To put things in perspective, wireline data rates with a voice-band modem can be as high as 28.8 kbps. In a T-carrier system, the data rate is 64 kbps for a DS0 channel and is 1.544 Mbps for a full T1 line (24 DS0 channels). Maximum user data rates for proposed PCS

[1] Table 4-3 is courtesy of Charles I.Cook, US West Technologies and Jason Losh, Motorola.

systems are found in Table 4-3. A high-tier system will provide a lower data rate than a low-tier system, and both will be lower than wireline rates.

Cost considerations for PCS

The issue of cost is one that is difficult to characterize. It is a function of economies of scale, supply, and demand. Technologies that are widely deployed and manufactured in large quantity naturally cost less than those for which there is little demand. The cost to the service provider is, in general, much higher for rural users than for urban users since, in the urban environment, one can expect a higher number of users per total infrastructure dollar. The issue of how data is transmitted is related to cost. To get the highest data rates, the voice encoder needs to be bypassed. As mentioned previously, this requires special equipment at both ends of the radio link. If there is large demand for this type of service then the cost will come down. However, the current PCS standards have no specific provision for bypassing the voice encoder.

Spectrum auctions for Blocks A and B were completed in mid-March, 1995. Winners who have announced the technology they will deploy, will use either the IS-95-based CDMA or the GSM-based TDMA technologies. Given this, it is expected that the cost of these technologies will decrease as multiple manufacturers compete for customers. Reduced cost for infrastructure should translate into reduced cost to the subscriber.

Competition between PCS operators as well as with the cellular providers should tend to drive the cost of service down. However, because they will be competing with the existing cellular operators for subscribers, the PCS providers will have to develop a large infrastructure before they can begin service; they will also have had to pay for spectrum. This will mean that their initial costs will be very high and will tend to drive the cost of service up. Therefore, competition and the initial high costs should tend to drive the cost of service in opposite directions.

4.5.4 Wireless Private Branch Exchange

The wireless private branch exchange (WPBX), while more complex than a cordless telephone, is not as complex as a PCS system. The cordless telephone is typically used in residences. It has a base station connected to the PSTN that is dedicated to a single telephone. No airtime charges are accrued. The PCS telephone is expected to be the next generation cellular handheld telephone. PCS telephones may use base stations deployed throughout a metropolitan area. The base stations are installed and operated by a telecommunications firm and users are charged based on the amount of time they use the system (airtime). The WPBX base station is connected to the PSTN through a building's existing wired private branch exchange (PBX). WPBX telephones can roam freely within the WPBX coverage area and communicate with any of the base stations in the building or perhaps throughout a campus. The WPBX system is user-owned so there are no airtime charges.

Most WPBXs are an adjunct to an existing PBX. They consist of a controller, base stations, and handsets (Kirvan, 1993). The base station provides the radio link to the handset. Base stations are connected to the controller by twisted wire pairs. The controller routes calls from the PBX to the appropriate base station. The handset is small and battery-operated.

WPBX systems are available that operate in the industrial, scientific, and medical (ISM) bands for unlicensed operations and at 860 MHz for licensed operations (Datapro, 1992b). The ISM bands are located at 902-928, 2400-2483, and 5725-5875 MHz. Systems in these bands operate under FCC part 15.247 rules. Transmitters in these bands have restrictions on transmitted power and must use either frequency hopping or direct sequence spread spectrum techniques to minimize cochannel interference. Part 15.247 users are not protected from interferers with higher priorities such as amateur radio operators or microwave heating devices.

In addition to operation in the ISM bands and at 860 MHz, WPBX systems will be developed for use in the unlicensed PCS band (1910-1930 MHz). This is a new band where users share spectrum resources and are required to abide by a spectrum-sharing etiquette. The advantage of this band over the ISM bands is that there are no priority users. Thus, if users follow the spectrum etiquette, they are assured the same privileges in the band as others. The disadvantage of this band is that there are previously-licensed users who have to be moved. Until they are moved, they have protection from unlicensed PCS interference.

Base station coverage for WPBXs ranges from a 50- to 100-foot radius with obstructed paths indoors to a 300- to 500-foot radius with unobstructed paths outdoors. The power output of WPBX handsets operating in the ISM bands (100 milliwatts) is considerably less than a handheld cellular telephone (600 milliwatts). Batteries typically supply 2 to 3 hours of talk time. Most handsets offer 9600 bps data interfaces for fax and computer applications.

Systems are available for small, medium and large buildings. A small WPBX may have up to 10 base stations and 30 users, a medium WPBX may have up to 20 base stations and 40 users, and a large WPBX may have several hundred base stations and 1000 users. The cost of a WPBX telephone is over $1000 when the controller and base stations are averaged into the cost of a telephone (Newton, 1993). This cost is more than that of a conventional desk telephone but not prohibitive to many businesses.

The WPBX is now used where there is a high concentration of workers needing mobile voice communications such as in a hospital or factory. Purchase of the telephones is typically justified by the increase in personnel productivity. As enterprises trim costs, more employees will be given WPBX telephones to enable them to be more productive. A disadvantage of WPBX telephones is that they cannot be used when out of range of a WPBX base station. To counteract this limitation, some WPBX telephones are now dual mode in that they are capable of working as a cellular telephone when outside the range of a WPBX base station.

4.5.5 Rural Radio and Subscriber Radio

Since the early 1950's, wireless access to the PSTN using analog FM radio technology has been used in rural areas. These systems, classified as rural radio, were not in widespread use, and in most cases, were requested by the subscriber as opposed to a service that was initiated by the service provider and offered to subscribers. Rural radio using analog FM technology was expensive, required too much AC power, was unreliable, and was spectrally inefficient. Even with all of these problems, there were some applications where this service was a better solution than the alternatives of providing wireline service or no service at all. According to Calhoun (1992, p. 153), the cost of installing a system for a single subscriber in an isolated area ranged between $3000 and $10,000.

Before the FCC final ruling was published on BETRS on Feb. 4, 1988, wireless access to the PSTN in rural areas in the United States was available under the FCC's Rural Radio Service classification. Frequencies were authorized for use in both the 150-MHz and 450-MHz bands. Besides the reasons mentioned above, rural radio was not used very much because licenses were only available with a secondary status. Licenses for Public Land Mobile Service were issued with a primary status. This meant that if a rural radio system caused interference to a Public Land Mobile Service licensee, the rural radio system licensee would have to eliminate the interference or cease operation. Furthermore, future licenses could be granted to the Public Land Mobile Service, but the Rural Radio Service system would still have to ensure that it did not cause interference, even if it had a pre-existing license. Therefore, service provided under the Rural Radio Service was not used very much, since it was a large economic risk (Schrage, 1989).

In the 1970's, a new type of system providing wireless access to the telephone network for fixed applications was developed. This system is called thin-route point-to-multipoint microwave (sometimes called subscriber radio). A basic subscriber radio system consists of a central station, any number of subscriber stations, and repeaters. A typical architecture for one of these systems is shown in Figure 4-12. The central station uses an omnidirectional antenna while each subscriber station uses directional antennas and is located within line-of-sight of the central station. Repeaters are then used to extend coverage beyond line-of-sight. A coverage area with radii of hundreds of miles can be achieved (Morris and Le-Ngoc, 1991). These systems typically use a subscriber station to serve a cluster of individual subscribers. Wire is used to connect the individual users to the subscriber station but a radio link connects the subscriber stations to the central station. In the past, subscriber radio was not a practical solution for users who were widely spread out over a large area, since it was generally too costly to provide a separate subscriber station for each user. Now, low-cost subscriber stations are available that are more suitable for serving isolated subscribers (Lloyd, 1994). For example, one manufacturer provides a low-cost subscriber station that can serve up to two users. Although subscriber radio can provide service to isolated subscribers, it is best used (most economical) in situations where there are clusters of users in very remote areas.

One implementation of a subscriber radio system, used extensively throughout the world, uses 64- kbps pulse-code modulation (PCM) and TDMA to provide the users with high-quality communications service. Using 60, 64-kbps trunks and assuming an average traffic intensity of

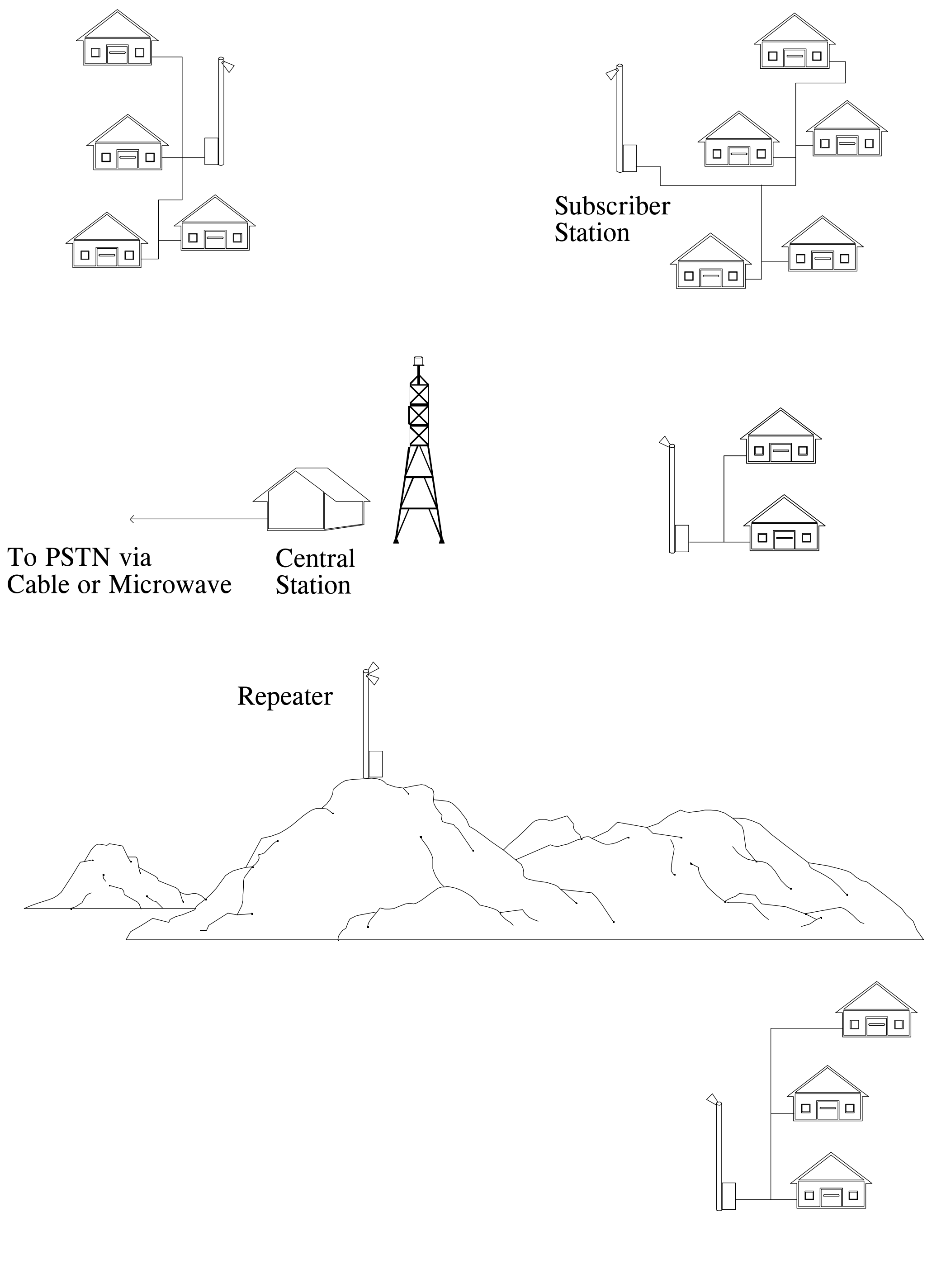

Figure 4-12. Typical subscriber radio architecture.

2.5 CCS, 670 subscribers can be served with a .01 probability of blocking from a single central station. This is the system capacity using a single central station. Systems can be easily configured at a lower cost to provide service to fewer subscribers. Subscribers can then be added later until the system capacity of the single central station is reached. Growth beyond this number of subscribers, assuming the same traffic intensity and grade of service, would require adding another central station and one or more subscriber stations. The system is capable of operating at frequencies between 1.3 and 2.7 GHz. A minimum system configuration, consisting of a single central station with no repeaters, will use 3.5 MHz of bandwidth for transmission from the central station to the subscriber stations and will use an additional 3.5 MHz of bandwidth for transmission from the subscriber stations to the central station. The use of additional central stations or the use of repeaters requires additional bandwidth. Typical systems will use a transmitter power of up to a maximum of about 3 watts (total power of all channels combined) for transmitters at both the central station and the subscriber stations. The typical area coverage of a system configured without any repeaters is about a 20- to 25-mile radius from the central station using antenna heights around 100 to 150 ft at the central station and around 30 ft at the subscriber stations. Range is dependent upon terrain but can, in general, be extended by going to higher antenna heights and/or by using repeaters. The absolute maximum range of the system is limited to about 445 miles because of propagation delay. Systems can be configured in a variety of ways depending upon the distribution of the subscribers in the area to be covered. Different subscriber stations are available to provide service for up to 256 clustered subscribers. Services that can be provided include voice, Group 3 and Group 4 fax, data up to 64 kbps, and Integrated Services Digital Network (ISDN) capability.

While subscriber radio is used in many locations throughout the world, it is used only on a very limited basis in the United States, since the necessary spectrum for point-to-multipoint microwave subscriber radio operation has not been allocated (Calhoun, 1995, p. 154).

4.5.6 Basic Exchange Telecommunications Radio Service (BETRS)

BETRS is a service established by the FCC that connects subscribers to the PSTN by means of radio. BETRS, as defined under the Rural Radio Service by the FCC, is a radio service between fixed subscribers and a central office that provides public communication service in rural areas. BETRS service can also be provided under the Domestic Public Cellular Radio Telecommunications Service, as a connection to the PSTN by means of cellular telephone to fixed subscribers in RSAs and rural areas within MSAs (Code of Federal Regulations, 1992). In addition to the aforementioned descriptions, BETRS, is defined by the FCC as a radio service operating in specifically designated frequency bands.

BETRS frequency bands

The 150-MHz and 450-MHz bands were authorized for BETRS on a coprimary status in the FCC final ruling published on Feb. 4, 1988. Authorizations included 18, 30-kHz channel pairs in the 150-MHz band and 26, 25-kHz channel pairs in the 450-MHz band. Additionally, 50, 25-kHz channel pairs were authorized for BETRS in the 800-MHz band on a coprimary status with the

Private Radio Service (Code of Federal Regulations, 1992). BETRS systems operating in the 800-MHz band cannot be used within 100 miles of the border of the top 54 MSAs. They also cannot be used within 68.4 miles of the borders of Canada or Mexico. BETRS may also be provided using cellular telephone frequencies but BETRS has secondary status while mobile cellular has primary status (Schrage, 1989). If any interference occurs to the mobile service, the BETRS operation bears the responsibility of correcting the interference or ceasing operation. Although BETRS operation in the cellular band has a secondary licensing status, it is expected that plenty of voice channels will be available in rural areas in the cellular band and that interference between BETRS and cellular mobile will not occur (Popp, 1989). The specific frequency allocations for BETRS systems can be found in the latest Code of Federal Regulations, Title 47, Part 22.

The goal of BETRS service is to provide a quality of service at least as good as wireline service. The subscriber should not be able to distinguish the operation of a BETRS system from wireline service and the BETRS equipment should interface directly with standard telecommunication interfaces.

BETRS architectures

BETRS systems can be classified by their type of architecture; they can be either point-to-multipoint or point-to-point systems. Point-to-multipoint systems are used when individual subscribers are spread out over a wide area. A typical configuration of a system such as this is shown in Figure 4-13. The BETRS system consists of a radio base station that can either be at the central office or at another location. Connection between the radio base station and the central office can be either via copper wire, fiber optic cable, or microwave link. Each individual subscriber has a dedicated antenna and radio. In this typical configuration it is common to use an omnidirectional antenna at the base station and directional antennas at the individual subscriber sites. One or more repeater sites may be used to extend coverage to another wide or localized area. Using repeaters does require additional frequencies, though. Service can also be extended by using a booster. A booster reuses and retransmits the same frequencies to other areas and hence is similar to a repeater without using additional frequencies. Care must be taken to ensure that co-channel interference between the original service area and the extended service area provided by the booster is minimized.

Point-to-point systems are used in situations where there are clusters of subscribers. An example configuration of this type is shown in Figure 4-14. The system components are similar to the point-to-multipoint systems in that there is a radio base station at the central office or at another location. In the simple point-to-point system, a subscriber station can serve many subscribers that are within a cluster. A directional antenna is used both at the radio base station and at the subscriber station. Individual subscribers are connected to the subscriber station via copper wire. Repeaters or boosters can also be used with point-to-point systems to increase the coverage range (Rural Electrification Administration, 1990).

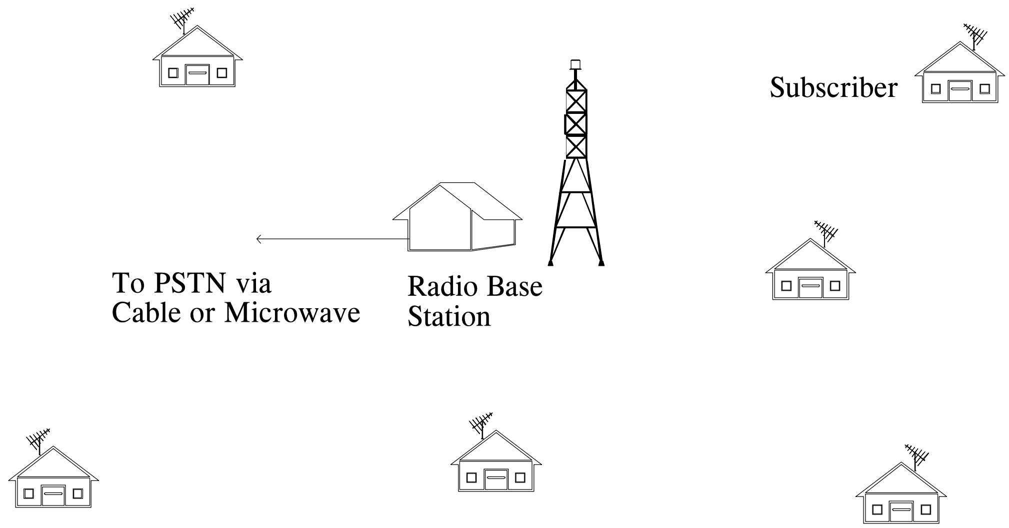

Figure 4-13. BETRS point-to-multipoint architecture.

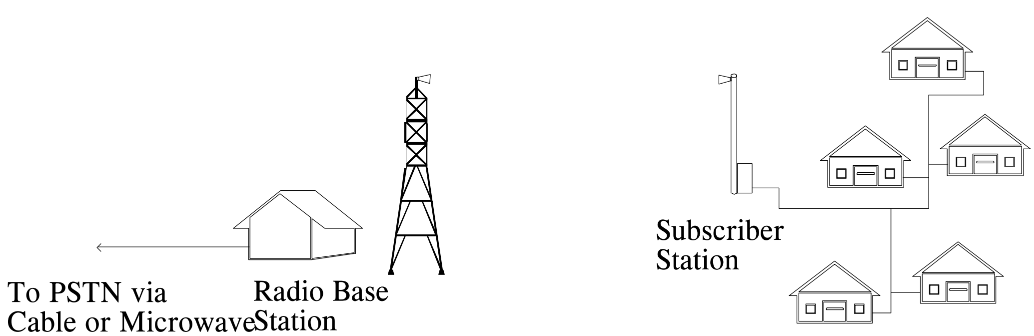

Figure 4-14. BETRS point-to-point architecture.

Example BETRS systems

A currently available BETRS system, providing a point-to-multipoint capability, consists of a radio base station, a central office terminal, and subscriber stations. The central office terminal connects with the central office switch and provides control and management of the entire BETRS system. A standard two-wire connection is used to interconnect the central office terminal (part of the BETRS system) to the central office switch. The radio base station can be located right at the central office terminal or can be located elsewhere. Connection between the radio base station and the central office terminal is made by up to six standard T1 lines. The subscriber station is located outdoors usually near the individual subscriber. Copper wire is then used to connect to the subscriber's standard telephone premise wiring.

The system allows for different configurations depending upon the number of subscribers to be served. Up to 24 channel pairs (25 kHz each) can be used for a given radio base station. TDMA is used to provide four individual voice circuits per channel. Therefore, up to 95 trunked circuits are available (one trunked circuit is used for system control) for subscribers. Up to 564 subscribers can be served with a .01 probability of blocking, assuming a traffic intensity of 2.7 CCS per subscriber using one radio base station. In general, service can be provided within approximately a 35-mile radius of the radio base station using typical base station antenna heights of 125 to 200 ft and subscriber station antenna heights of about 30 ft. Transmitter power at the radio base station is approximately 4 watts per channel and at the subscriber station is about 2 watts. This system can support data modems at speeds up to 2400 bps and Group 3 fax in addition to wireline quality voice service. For service to areas where clusters of subscribers exist, a subscriber station is available that will serve up to 64 users. Each individual user is connected to the subscriber station via copper wire.

Another commercially available BETRS system uses a point-to-multipoint configuration with a radio base station providing a radio link to individual subscriber stations using FDMA. This system can provide service to up to 48 subscribers using a single base station with 6, 25-kHz frequency pairs. A grade of service with a probability of blocking of .05 can be provided assuming a traffic intensity of 2.15 CCS per subscriber for the busiest hour. Each subscriber line is connected to the central office via a standard two-wire analog connection on the radio base station. Analog FM is used with a base station transmitter power of 1.5 watts per channel and a subscriber station transmitter power of 2 watts. A 30-mile radius coverage area can be provided assuming line-of-sight propagation, a base station antenna height of about 100 ft, and a subscriber station antenna height of 20 to 25 ft. In addition to high-quality voice service, data modems with speeds up to 14.4 kbps and Group 3 fax can be supported. Point-to-point systems are also available to serve subscribers with heavy anticipated usage.

Projected market for BETRS

A significant amount of effort has gone into estimating the potential number of subscribers for wireless access to the PSTN. Equipment manufacturers, service providers, and the Rural Utilities Service (RUS) have been interested in this information.

One estimate of the potential market for BETRS in rural areas in the United States was developed by the Rural Electrification Administration (REA; now called the RUS). The overall estimate was developed from three separate estimates. First, the unserved phone demand was estimated. Unserved phone demand is the number of potential subscribers in an uncertified land area. An uncertified land area is a region where there is no certified telephone company. The unserved phone demand is based on estimating the number of potential subscribers who live in an uncertified land area, want telephone service, and can afford it. An estimated potential subscriber density (number of potential subscribers per square mile) in uncertified land areas was determined and multiplied by the amount of uncertified land area (in square miles). The REA estimated that the unserved phone demand in the United States was approximately 150,000, but suggested that this was a very conservative estimate and that the actual number was probably much higher (Schrage, 1989). In general, the unserved population in very remote areas is quite spread out, typically having less than 10 customers in a given area. However, an example of a very large unserved population all in the same area is the Navaho Indian reservation where estimates indicate that up to 80,000 people do not have telephone service (Schrage, 1989).

Next, the number of homes in certified areas (regions where a certified telephone company did exist) that did not have phone service was estimated. According to a survey by the Telephone and Data Systems Company, most of the households that did not have telephone service had no service because they didn't want it; only 5.8% of the unserved households had no service because none could be provided. Under the assumption that this percentage was essentially the same throughout the United States, and using an estimate of the number of homes without telephone service in the United States (with the assumption that all these homes were within certified areas), the REA estimated that there were approximately 330,000 potential subscribers in certified areas.

Finally, the number of potential subscribers to use BETRS to achieve an upgrade in service from 4- or 8-party line service was determined. This estimate was based on the number of known party line subscribers of REA borrowers (approximately 400,000) from the December 1983 annual statistical report on rural telecommunications borrowers.

The overall REA estimate of potential BETRS subscribers in the United States based on these three factors was approximately 880,000. The REA considered this a very conservative estimate. This type of projection of the number of potential subscribers is difficult to determine accurately. This estimate was made by the REA based on data from 1984 or earlier; hence, these estimates do not necessarily reflect the current situation. Certainly the estimate of the number of known party line subscribers of REA borrowers has changed drastically since 1984. By the end of 1994, the number of 4- or more party line subscribers of REA borrowers had dropped to about 28,000 (Rural Utilities Service, 1995). In addition, not all of the party line subscribers would be converted to single-party service using BETRS. In some cases, wireline would be more economical than wireless access. Calhoun (1992, p. 186) estimated that for 20 - 50% of rural party line subscribers, wireless access would be less costly than wireline access. The estimate of the number of potential subscribers to use BETRS for party line upgrade only included service providers that were REA borrowers; service providers that did not borrow from the REA were not included. Two-party line service was not included in the REA party line upgrade estimate.

The REA estimate did not take into account the addition of new subscribers. In the United States, about three million new access lines are provided each year. Of this, Calhoun (1992, p. 186) estimated that 20% of these access lines are in rural areas and that 10% (300,000) are suitable for wireless access. Also, there is potential for BETRS to replace old and deteriorating copper wire in rural areas. Calhoun (1992, p. 186) estimated that approximately five million lines require replacement or significant repair in the United States every year. Of this, he estimated that about 20% of these lines lie in rural areas and that several hundred thousand lines would be appropriate for wireless replacement.

Several other studies concluded that the demand for wireless access in rural areas in the United States would be approximately several hundred thousand lines per year with a total potential market of several million lines. While these studies have shown this kind of demand, actual penetration of BETRS has been significantly less than these studies have indicated. According to Calhoun (1992, p. 38), as of the early 1990's, there were more than 50 BETRS systems operating in the United States with several thousand subscribers.

The REA conducted a survey regarding the potential use of BETRS in which more than 330 REA borrowers responded. From this survey, 91% of the demand for BETRS systems came from Michigan and states west of the Mississippi River (excluding Missouri and Utah). The 9% demand for BETRS east of the Mississippi River came primarily from areas in and around the Appalachian Mountains. The survey showed overwhelmingly that potential subscribers would demand single party service even though party line service might provide a more inexpensive means of service. The ability to provide pay phone service was found to be a service that was in demand. Telephone lines for businesses were shown to be in high demand. Finally, the survey showed that the use of wireless access would be the greatest in homes, cottages, ranches, and camps. The next greatest usage was found to be for mining operations and forest ranger sites. Numerous other industries, businesses, groups, and organizations were listed as potential users of wireless access to the PSTN.

4.6 Radio Paging

Radio paging began in 1949 with the allocation of frequencies in the low VHF band (30-50 MHz) exclusively dedicated to one-way signalling services. Subscribers used AM receivers, listened for an operator to announce their number, and then called the service to receive their messages. Selective addressing (the ability to choose one individual pager from the group) was introduced in the mid 1950's and FM was first used in an experimental paging system in 1960. This experimental system also featured fully automatic operation with no operator intervention. It operated within the high VHF band at 150 MHz, a frequency band that was allocated for paging several years later. These early pagers emitted an alarm when addressed; pagers that could display phone numbers were introduced in the 1980's. Pagers with alphanumeric displays made their debut in the early 1990's. In addition to complete messages that can be sent and stored in these pagers, a number of other services such as stock market and sports score reporting are available.

Pagers typically use frequency-shift keying (FSK) modulation with a bandwidth of 20 kHz and a maximum frequency deviation of 5 kHz. Pagers operate at frequencies in the 30- to 50-MHz range, the 150- to 170-MHz range, the 450- to 470-MHz range, and around 900 MHz. Addressing is accomplished by using tones or through a digital protocol that was devised by the British Post Office in 1978. The tone formats are restricted to tone alert or tone plus voice message (a short spoken message follows the alert tone) paging only. These formats fall into two categories: a two-tone system and a 5/6-tone system. In the two-tone system, a sequence of two tones out of sixty that are available uniquely identify a given pager. This system is used in older equipment but is still supported. It allows 3,540 unique paging addresses but typically requires four seconds or longer to transmit an address because of stability considerations in the analog filters. The 5/6-tone system uses a sequence of five or six tones out of twelve that are available to uniquely identify a given pager. The 5/6-tone system can address up to 100,000 pagers and features an addressing rate of five pagers per second (200 milliseconds per address).

Digital paging gained widespread usage in the early 1970's because of the speed advantage it offers over tone-dependent methods. Digital formats also offer error correction and battery-saving features that are not available in tone-operated systems. The public domain Post Office Code Standard Advisory Group (POCSAG) format is commonly used to provide two million distinct addresses and a data rate of 2400 bps. This translates to about 75 calls per second for alarm-only paging, 25 calls per second to distribute a ten digit message, or about 6 calls per second for a 40 character alphanumeric message.

Radio paging usage is expected to expand significantly in the near future. Usage in 1994 encompassed 24.5 million units and is expected to increase to 56.2 million by the year 2000 and 92.2 million by 2005. One driving force for this expansion is the narrowband PCS spectrum recently auctioned by the FCC that will be used for two-way paging, probably beginning next year. Initially this two-way capability will allow users to send preprogrammed responses and will be used to alert local service providers when a user changes coverage areas. Full alphanumeric two-way operation is expected to develop rapidly. The primary market for this service will probably be users of laptop computers and personal digital assistants (PDAs). In these cases, the paging device will probably be a plug-in card.

The impact of radio paging in rural areas must be assessed with two primary considerations in mind. The first is the relatively low startup costs associated with the industry, allowing small local services to exist in limited rural markets. The second is the aggressive marketing that has been recently used by the radio paging industry to create an awareness of paging as a consumer and retail service, rather than just a business application. Pagers that are smaller and produced in different shapes and colors have been used to increase retail sales, and the advent of new, more consumer-oriented services should also produce the same effect. Paging also makes efficient use of the radio spectrum.

4.7 Packet Radio

Packet radio is a method of transferring digital data over a radio channel. A radio channel has several properties that can corrupt digital data as it moves through the channel. One of these properties is noise. Thermal noise generated within the radio equipment can distort the digital signal causing the wrong digital symbol to be detected. Broadband noise sources such as electrical appliances that contain motors, automobile ignition systems, and circuits that involve switching relays can produce noise that corrupts digital data. Another property of the radio channel is fading. The received signal level can vary as a function of both time and location. The signal level can fade down to a level that is too low for the digital data to be detected. This can introduce errors in the received data. Interference is another property that can corrupt digital data that is being sent through a radio channel. Interference comes from many sources. A complex mixing of various transmitted signals from nearby transmitters will cause interference. A transmitter that is in need of maintenance can produce signals on the wrong frequency, causing interference. Because of the effects of noise, fading, and interference, the radio channel can be a hostile environment to digital data. Packet radio was created to combat these hostile properties.

In packet radio, a short message, entered by a user, is converted into a stream of digital characters by the electronic hardware. Transmitting this stream in a single radio transmission would block other users of the radio channel for an unacceptably long period of time. If one or more of the characters in this single long transmission were to be corrupted, the entire message would have to be resent, again blocking other users of the radio channel for an additional period of time. Packet radio avoids this problem by dividing the stream of characters into many smaller streams called packets. A packet can be any length up to a predefined maximum. The maximum length is a trade-off between efficiency and robustness. Smaller packets are more robust and better able to get through difficult radio channel conditions; however, smaller packets generate more overhead. The larger overhead in smaller packets results in a decrease in throughput, causing the message to take longer to get through. For a typical packet length of 512 characters, a 2048-character message takes a minimum of four transmissions to send. If the data becomes corrupted, a packet would have to be resent resulting in an additional time delay. However, having to resend a packet is faster than having to resend the entire message.

The receiving station needs to know when a packet has been corrupted and needs to be resent. The procedure for determining if a packet has been corrupted is known as error detection. In error detection, extra characters are added to each packet before it is transmitted. These extra characters are determined from operations performed on the message characters. The receiving station performs the same operations on the message characters in the received packet and compares the result to the extra characters in the received packet. If they agree, the data was received correctly and an acknowledgment is sent to the sending station. If there is disagreement, the receiving station sends a request to the sending station to retransmit the packet.

Sometimes, only a few characters are corrupt in a packet. It seems wasteful to resend all of the characters (for example, 512 characters) to correct only a few characters. Therefore, error correction techniques have been developed to allow the receiving station to calculate which characters are corrupt and what the correct character should be. These techniques work in a manner similar to error detection by adding additional characters to the packet. These additional characters increase the time to transmit a packet but they increase the overall throughput by reducing the probability that a packet will need to be resent.

Additional characters are added for control purposes. The receiving station needs to know how to route the incoming packets and who to bill for the transmission. Therefore, the addresses of both the station sending the messages and the station to receive the message are added to each packet. Sometimes, special start and end characters are added to aid in synchronizing the radio receiver. Not all transmitted packets carry user information. Control packets are transmitted to keep the sending station and receiving station synchronized to ensure that the order of the information-bearing packets is preserved. An additional character is added to define whether a packet contains user data or is a control packet.

In a typical packet radio exchange, an information-bearing packet is transmitted. The receiving station decides whether it received a good or corrupt packet. The receiving station transmits back to the sending station either an acknowledgment of a good packet or a request to resend the packet. These transmissions continue back and forth until the entire message is sent. Sometimes, the sending station does not receive a response from the receiving station. This could happen if the receiving station does not receive a transmission from the sending station. It could also happen if the sending station does not receive a response from the receiving station. If the sending station does not receive a response from the receiving station, the sending station will wait indefinitely for the response from the receiving station. To prevent this, a timeout period is defined for the system. If the receiving station's response is not detected after the timeout period has expired, the sending station will retransmit the last packet. The sending station will continue to timeout and retransmit until either the receiving station's response is detected or a maximum number of retries is reached. Typically, the timeout value has a range of 2-6 seconds. This cycle of waiting and retransmitting is the main cause of delays in a packet radio system. Providing adequate radio coverage helps to minimize this delay.

With packet radio, it is possible to allow more than one user to send a message at the same time. The packets arrive at the receiving station interleaved. This is not a problem since the receiving station has the intelligence to sort and recombine the packets to put the original messages back together again. Unfortunately, throughput lowers quickly when multiple users simultaneously share the same channel. Throughput for each user is decreased to one-half the original rate when two users simultaneously share the same channel. A proportionate decrease in throughput for each user occurs as additional users simultaneously share the same channel. This property of packet radio is combated by providing more channels and/or reducing the coverage area to decrease the chances of having multiple simultaneous users on a channel.

Packet radio is a very useful tool for sending a message through the radio channel. It has built-in schemes to combat the problems inherent in data transmission over the radio channel. Message content security can be added easily when the packet size is kept small. Many commercial providers take advantage of the fact that billing is made easier if the customer is charged on a per packet basis. In this way, the customer is billed only for the airtime that the message consumes.

Commercial packet radio services

A popular use of packet radio is to provide a radio channel from a service provider to an end user. The end user can be either mobile or at a fixed location. To use this service, a special packet radio modem is required. The modems are available for between $500 and $800. The modem will work with various desktop computers, notebook computers, and even some of the new, small personal digital assistants. There are several commercial services currently available using packet radio technology. They are providing a means for organizations to send messages and information to their personnel in the field. The communication is two-way so field personnel can send a response back or initiate a message. Automatic roaming is available on some systems. A user can travel from one coverage area to another and their messages will follow them automatically. Field personnel can use this service to search a database for needed information. Transportation services can send messages used to track the location of goods. Written work orders can be dispatched through this service.

Connectivity is not limited to interorganizational destinations. Third-party service providers are offering gateways to users that do not have a direct connection. A gateway is available to send electronic mail to users of the Internet. News and stock quotes are available. A user can send a text message and have it sent to a telephone fax machine. A telephone operator is available to take a message and send it to a user of the packet radio service. These services are available for under $100 per month on an unlimited usage basis or a price per packet basis.

Typical commercial packet radio systems operate at data rates of 4.8 kbps, 8.0 kbps, and 19.2 kbps. The lower rate service limits the uses to short (under 2 Kbytes) messages. The middle rate service allows for large messages (under 20 Kbytes). The higher rate service makes it practical to transfer large amounts of data. Internet services other than electronic mail become practical. Small to medium size databases or spreadsheets can be transferred. Browsing a text version of the world wide web becomes possible.

Coverage areas for packet radio systems

The coverage areas for current systems are targeting the areas of high population density. Two commercially available services claim to cover 90% of the business population in the United States. Over 10,000 cities have coverage by one or more service providers. There are many small towns included in the listed coverage areas but these small towns are located near big cities and are being covered as part of the big city network. For example, in Colorado, Erie (population 1258), Frederick (population 988), and Dacono (population 2228) are located in an area that would appear to be rural to a traveling motorist. These towns are located 15 miles from the Boulder metropolitan area (approximate population 83,000). In Virginia, both Elkton (population 1935) and Grottoes (population 1455) have coverage because they are located about 15 miles from Harrisonburg (approximate population 31,000). The rural areas that have coverage are within about 15 miles of a nonrural city.

Packet radio systems can be divided into two categories: those that operate on FCC-licensed frequencies and those that do not. The licensed systems deploy base stations around the desired coverage area and operate on frequencies between 800 MHz and 1000 MHz. The typical range of a base station is 10-15 miles. The base stations are located to give contiguous coverage of an area. Some overlapping is encouraged to strengthen system operation in the fringe areas. The base stations can operate on up to 16 frequencies simultaneously so that one base station can provide acceptable service for up to 50 users simultaneously. Since it is highly unlikely that all users will send a message at the same time, up to 500 users can be covered by one base station. To serve even more users, the base station's power can be lowered allowing more base stations to be installed in an area. To prevent running out of frequencies, the frequencies are reused in nonadjacent coverage areas.

Adapting current commercial systems for rural areas

Current commercial packet radio technology emphasizes covering the densely populated areas. With some modifications, this technology could be used to provide coverage in a rural area. Since the population density is low in a rural area, an approach would be to increase the coverage area of each base station. This could be accomplished by using higher antenna towers. A 500-ft tower provides approximately a 32-mile radius of coverage. A 1000-ft tower would extend coverage to approximately a 45-mile radius. Transmitter power or antenna gain would have to be increased to make up for the higher loss caused by the increased distances. Higher transmitter power translates into higher costs per user in the rural areas.

Since packet radio is a two-way service, some changes are needed at the user's end as well. The user's modem would have to transmit over increased distances. The user's transmitter power would need to be increased. This could be mitigated by using an antenna with higher gain; however, high gain antennas are physically larger and this could impact the portability of the equipment. Current packet radio systems provide highly portable terminals. Larger capacity batteries will be needed to allow a reasonable operating time. These batteries are physically larger and will adversely affect portability.

If the rural user's need is at a fixed location, directional antennas pointed at the base station could be used. Using a directional antenna provides more antenna gain and requires less power from both the user's and the base station's transmitter. Lowering transmitter power would result in lower costs per user.

Amateur radio packet systems

The previous discussion centered on commercial packet radio technology. Packet radio technology is being used by amateur radio operators as well. The amateur radio operators have built packet radio systems that cover several hundreds of miles using VHF and UHF frequencies. Messages, generally under 5 Kbytes in size, can be sent over these networks. Currently, a popular data rate for end users is 1200 bps. Systems with data rates of 9600 bps are gaining popularity. Even higher data rates, such as 19.2 kbps, are being used on major traffic forwarding routes in some parts of the United States. Research is being conducted by amateur radio operators to further increase the data rates to 56 kbps and even 2 Mbps to increase the amount of traffic that can be handled. Experimentation continues with TCP/IP (the protocol used on the Internet) over these networks. Amateur radio operators have linked their home stations into the Internet using TCP/IP.

Amateur radio operators are interested in providing coverage to fellow operators in rural areas outside the metropolitan cities. They achieve this by installing wide area coverage packet radio repeaters. The common type of repeater operates on a single frequency. These repeaters listen for packet radio transmissions and then retransmit the packets on the same frequency after a short time delay. These repeaters are placed on top of tall towers, hills, and mountains. When using one of these repeaters, an operator can greatly increase the communications range. For example, consider the case of an operator with a 50-ft tower. The communications range will be about 10 miles. Now suppose that there is a repeater that is 40 miles away and on top of a 500-ft tower. The operator could use this repeater to send a message to another operator with a 50-ft tower that is 80 miles away. To get even more range, amateur radio operators can link several of these repeaters together to send a message over 250 miles or more. This type of technology could be used to provide messaging services to rural areas. With further increases in link speed, file transfers and other high data rate services become possible.

Amateur radio operators have noticed that with several simultaneous users, the throughput of the single frequency repeater can drop dramatically. This is due to collisions of simultaneous packet transmissions. The packet radio modems are designed not to transmit on a busy frequency. They will wait until the frequency is clear before transmitting. Occasionally, two stations that cannot hear each other will transmit to a wide range repeater at the same time. The signals collide at the repeater and neither one is decoded properly. Amateur radio operators have solved this problem by using dual frequency repeaters. The dual frequency repeater receives on one frequency and simultaneously retransmits the signal on another frequency. By using a dual frequency repeater, two stations that do not normally hear each other will be able to. This prevents the collisions and raises the throughput of the system. A separate link frequency is used to link this type of repeater with its neighboring repeaters. A repeater like this can allow packet radio technology to serve a large rural area with a high level of throughput.

4.8 Wireless Local Area Networks

Computer local area networks (LANs) are commonly connected by cable. Cable provides an excellent transmission media and supports data rates in the tens of Mbps for Ethernet and Token Ring technologies and hundreds of Mbps for fiber distributed data interface (FDDI) technologies. There are applications, however, that cannot use cable or are prohibitively expensive if cable is used. Frequent moves of point-of-sale terminals in the retail environment make wireless access more cost-effective than cabled access. Mobile inventory scanning in warehouses and stores requires a wireless scanner. Some building architectures make cable installation prohibitively expensive. Wireless LANs (WLANs) are well suited for all these applications. Both WLANs and wired LANs are typically user-owned systems (i.e., there is no service provider and hence users do not incur service charges).

Because WLANs are built for many different frequency bands, bandwidths, and environments, there are wide variations in area coverage provided and data rates supported (Bantz, 1994). WLANS are available that operate in the infrared (IR) band, in the industrial, scientific, and medical (ISM) bands, and in the Digital Termination Services (DTS) bands covering 18.82-18.87 and 19.16-19.21 GHz.

IR energy cannot pass through walls, ceilings, or floors. This is considered an advantage because it enhances the security of a WLAN link and decreases interference between WLAN modems. IR WLANs operate in a line-of-sight or diffuse mode. In the line-of-sight mode, a narrow, unobstructed beam is transmitted across the room. Distances between modems of 200-300 ft and data rates better than 10 Mbps are possible; however, the link is completely disrupted by objects moving through the narrow beam. In the diffuse mode, an omnidirectional beam is transmitted from the ceiling of a room or by spreading a narrow beam by bouncing it off the ceiling. When bouncing a narrow beam off the ceiling, the roughness of the ceiling in comparison to the IR wavelength spreads the IR beam omnidirectionally. Distances between modems and data rates when using the diffuse mode are less than those when using the line-of-sight modes. Distances between modems of 30 ft and data rates of 1 Mbps are typical when using diffuse mode IR.

Radio waves in the ISM bands are able to penetrate walls, floors, and ceilings to some extent and diffract around hall corners and doors as well. This is considered advantageous because it can potentially reduce the number of base stations needed for building coverage. ISM WLANs with omnidirectional antennas operate over distances of 100-300 ft indoors and up to 1000 ft outdoors. Operating distances are shorter indoors because of more obstructions such as walls, partitions, and furniture. Data rates of ISM WLANs vary from 250 kbps to 16 Mbps (Boyle, 1995; Mier, 1994).

Operation in the DTS bands requires licensing. Channels in the DTS bands are 10-MHz wide and products with data rates of 15 Mbps are available. These systems can operate over distances of 50 ft in closed offices and 150 feet in open office areas. Signals around 18 or 19 GHz can penetrate a drywall partition but cannot penetrate an exterior masonry wall or a concrete floor. This allows system planners to isolate cells on different floors in a building. Another advantage of the DTS bands is the reduced size of the antennas as compared to the ISM band. This reduced size enables designers to use advanced antenna technologies to maximize performance (Freeburg, 1991).

WLANs are available for battery-operated mobile terminals such as laptop computers and personal digital assistants. WLAN manufacturers provide software that allows ad hoc networks to form with two or more of these mobile terminals. These ad hoc networks are an excellent solution for providing computer communications in locations where no installed LAN is available (such as a construction site), or an installed LAN is present but a group of users wants their own, independent network (such as a group of sales people in a customer's building). Users can easily join and terminate their association with an ad hoc network, although permission to join the network can be denied for security reasons.

When mobile WLAN terminals need to use a building's LAN infrastructure, wireless access points are incorporated into the wired LAN. These access points provide connectivity between wired and mobile terminals. If mobile terminals need to be able to communicate with wired terminals throughout a building, multiple access points may be needed.

Stationary WLANS, like mobile WLANs, can form ad hoc networks or use access points to communicate with wired terminals. Stationary WLAN terminals give up mobility but they do not have the stringent power savings requirements demanded by battery-operated mobile WLAN terminals since AC power can be used. Stationary WLANS are also able to use larger, and therefore potentially higher-gain antennas than mobile WLAN terminals.

The cost of WLAN access points is about $1800, and the cost of terminal adapter cards is about $600 (Boyle, 1995). Access points are not necessary for wired LANs, and the adapter cards for wired LANS are about three times less expensive than WLAN adapter cards. Therefore, WLANs are considerably more expensive than wired LANs. Trade magazines report that installation of WLAN equipment is manageable by most personal computer users. Some products offer radio signal quality indicators to allow the user to position stationary terminals for best reception. WLAN network size is sometimes limited by system design; however, many products are capable of expanding to hundreds of terminals.

Services provided by WLANs are only limited by bandwidth. WLANs historically provided wireless extensions of existing computer networks whose primary function was data transmission. Products performing data collection from mobile terminals were a natural extension of data transmission. With the advance of computer multimedia products, however, computer networks are now transmitting compressed voice, images, and video. Data rates available with WLANs provide enough capacity to carry multimedia traffic also. The IEEE 802.11 WLAN standard supports real-time voice and video traffic in addition to data transmission. Thus, services such as voice telephony and video teleconferencing are possible.

Rural enterprises will experience increased demands for mobile computing just as urban enterprises do. The merging of voice recognition, bar code scanners, and radio frequency identification (RFID) devices with WLAN mobile data collection is likely to benefit rural enterprises by controlling costs through inventory management, quality control, and resource allocation. In one example application, a portable computer with a WLAN can be used with voice recognition to provide forklift operators in a warehouse a hands-free method of interacting with inventory control software. Bar code scanners with WLAN interfaces can be strapped onto warehouse workers arms so both hands are free for other tasks. A WLAN mounted on a factory assembly line machining tool can interrogate a subassembly's RFID to determine what needs to be done (Kachmer, 1994).

4.9 Wireless Digital Modems

Wireless digital modems (WDMs) are used to perform LAN connectivity or telephone trunking over distances from 1-30 miles. Available data rates are not only high enough to provide LAN connectivity but can also support video teleconferencing and high data rate multiplexers with data, voice, and video channels. WDMs are used as permanent links but are also frequently used as a temporary link until a cabled link can be installed or as an emergency backup link to a cabled link. WDMs operate in the licensed microwave bands, the DTS bands, the IR band, and the ISM bands.

Modems in the licensed microwave bands (2, 4, 6, 8, 11, 18, 23, and 30 GHz) operate over distances of 1-15 miles and support data rates of 1.5-45 Mbps (Datapro, 1992a). In urban areas there is a trend to use the higher bands such as 18, 23, and 30 GHz to avoid congestion in the lower bands. Rural areas, however, may not be as congested in the lower bands as the urban areas. The cost of WDMs may be as low as $10,000 for lower frequency and lower data rate WDMs and as high as $80,000 for the higher frequency and higher data rate systems. Transmit power is usually 100 or 200 milliwatts, but it may exceed 1 watt. Highly directive dish antennas at the transmitter and receiver with gains of 30 dB or more are commonly used. Modems are also available in the DTS bands that have data rates up to 6 Mbps and operate over distances up to 1 mile.

IR WDMs (Datapro, 1991) are used in congested urban areas; however, they may also be useful in rural areas because of their high data rates. Under ideal conditions, IR WDMs are capable of data rates up to 45 Mbps and operating distances up to 10 miles. Units with data rates of 1.5 Mbps and operating distances of 1-2 miles are typical. The main disadvantage of IR WDMs is the outage time due to foggy atmospheric conditions.

With the appropriate combination of power amplifier and antenna gain, WDMs in the ISM bands (Greir, 1995) are able to span up to five miles with yagi antennas at the transmitter and receiver and up to 20 miles with a yagi antenna at the transmitter and a dish antenna at the receiver. Data transmission rates are dependent upon whether the data is transmitted asynchronously or synchronously. In general, asynchronous data transmission is much slower that synchronous data transmission. For WDMs operating in the ISM bands, asynchronous data rates up to 38.4 kbps are possible while synchronous data rates can meet T1 rates (1.544 Mbps). One product is available that can operate at a data rate of 8 Mbps at distances over one mile.

A pair of WDMs in the ISM band may cost as little as $10,000. With network intelligence added, the costs rise to about $15,000-$25,000 a pair. In general, WDMs are easy to install and operate. Many WDMs can be configured by personal computer software and can be interrogated by a remote computer to determine their operational status.

A demonstration project by NASA's Lewis Research Center (Masud, 1995) shows one way that rural communities may benefit from WDM technology. Two Internet hubs were installed in Cleveland, Ohio. WDMs were then used to connect between the two hubs and the local schools. Now all the local schools have low-cost wireless access to the Internet. This type of connectivity could easily be applied to rural schools.

4.10 Satellite Systems and Services

The discussion of satellite systems in this report is limited to those systems that provide communication services, that is, satellite systems typically known as communication satellites. Communication satellites have two major technical and cost advantages over terrestrial communication technologies. One is the ability to broadcast signals over the entire coverage area for the satellite, which can be as large as about one-third of the Earth. The other is the ability to provide reliable communication between any pair of points in the coverage area at the same cost—independent of distance or characteristics of the intervening terrain (such as water, deserts, or mountains).

Commercial communication satellite services began in the mid-1960's with the establishment of INTELSAT, a multinational organization with well over 130 member nations today. An organization known as the Communications Satellite Corporation (COMSAT) also was established in the early-1960's and became the United States' representative in INTELSAT. INTELSAT made the decision to build and launch geosynchronous[2] satellites to provide international communication services. These first commercial applications of satellites provided international telephone and television program transmission, primarily between the United States and Europe. From the launch of INTELSAT I in April 1965 to the present time (INTELSAT VII-A (706), launched May 17, 1995 and placed in service July 8, 1995), INTELSAT has been a dramatic succession of increasing satellite capacities, larger Earth-station networks, and decreasing costs for transmission.

As the costs for satellite transmission decreased, it became practical in the mid-1970's to develop domestic satellite systems to support telecommunications networks covering much smaller areas than all of the area of Earth visible from a satellite in geostationary[2] orbit (GSO), e.g., a continent. The first domestic satellite for the United States, Westar I, was built by Hughes Aircraft, launched in April 1974, and operated by Western Union. This C-band satellite had 12 transponders, with 36 MHz of bandwidth for each transponder, that could provide 7,200 voice circuits or 12 television channels. By the end of 1995, the United States is expected to have 14 satellites with C-band capabilities and 25 satellites with Ku-band capabilities that will provide a total of 604 transponders with 25,557 MHz of bandwidth in geostationary orbit. Low-Earth orbit (LEO; nonsynchronous) satellite systems also are being developed that will rapidly add to the total space systems' capabilities to provide telecommunications.

Domestic satellite communication began with "fixed" service, but today many applications have successfully extended into mobile and broadcast services. Fiber optics, submarine cables, and microwave radio transmission technologies provide strong competition to satellites for wideband service between geographically fixed locations. But, there is no effective alternative to satellites for providing wideband service to mobile terminals. Other services in which satellites have a

[2] The terms "geosynchronous orbit" and "geostationary orbit" sometimes are used interchangeably. In fact, a geosynchronous orbit is any orbit for which a satellite's period of revolution is equal to the period of rotation of the Earth about its axis; a geostationary orbit is a geosynchronous orbit that is circular in the Earth's equatorial plane. For this case, the satellite's period of revolution not only is equal to the period of rotation of the Earth, but the satellite also remains directly above a fixed point on the equator, often referred to as the subsatellite point.

substantial inherent advantage, that are just beginning to be exploited, are broadcast transmissions to, and data collections from, many terminals whose locations (probably, widely dispersed) are not known a priori.

This section of the report discusses communication satellite systems that include both geostationary and nonsynchronous satellites, providing services that include fixed-satellite service (FSS), broadcasting-satellite service (BSS), and mobile-satellite service (MSS). The mobile-satellite service is divided further into aeronautical mobile-satellite service (AMSS), maritime mobile-satellite service (MMSS), and land mobile-satellite service (LMSS). The various communication satellite services are defined by the Federal Communications Commission (FCC, 1994) as noted below.

> Fixed-Satellite Service. A radiocommunication service between earth stations at given positions, when one or more satellites are used; the given position may be a specified fixed point or any fixed point within specified areas; in some cases this service includes satellite-to-satellite links, which may also be operated in the inter-satellite service; the fixed-satellite service may also include feeder links for other space radiocommunication services.
>
> Broadcasting-Satellite Service. A radiocommunication service in which signals transmitted or retransmitted by space stations are intended for direct reception[3] by the general public.
>
> Mobile-Satellite Service.[4] A radiocommunication service:
>
> 1) between mobile earth stations and one or more space stations, or between space stations used by this service; or
>
> 2) between mobile earth stations by means of one or more space stations.

Typical applications, types of satellites used, and the frequency bands allocated for each type of communication satellite service for the United States are shown in Table 4-4.

The following three subsections discuss fixed-satellite service, broadcasting-satellite service, and mobile-satellite service, in that order. However, it will become apparent that the distinctions between fixed-satellite and broadcasting-satellite services are not entirely distinct and separate. For example, the television programming distributed by FSS and intended for reception by local broadcasters and cable companies, but is also being received by several million home television receive-only (TVRO) terminal owners, could be considered a de facto broadcasting-satellite service.

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[3] In the broadcasting-satellite service, the term direct reception encompasses both individual reception and community reception.

[4] This service may also include feeder links necessary for its operation.

Table 4-4. Typical Services Offered by Domestic Communication Satellite Systems in the United States

Service Type	Typical Applications	Types of Satellite	Allocated Frequency Bands (GHz)[1]
FSS	Voice (telephone), data (both voice-band and wideband), video teleconferencing, video program distribution, radio program distribution, news gathering, distribution for remote printing and publishing. Today, virtually every major country of the world has (or is planning) its own communication satellite system.	GSO	C-band 3.40-4.20; 5.850-6.725[2] 4.50-4.80; 6.725-7.025[3] Ku-band 10.95-11.20; 14.00-14.50[2] 11.45-12.20; 12.70-12.75[2] 10.70-10.95; 12.75-13.25[3] 11.20-11.45[3]
BSS	Radio and television program distribution directly to homes and businesses.	GSO	Ku-band 12.20-12.70; 17.30-17.80[3]
MSS	Voice and data communication to and between aeronautical, maritime, and land-mobile users.	Non-GSO & GSO LEO & GSO	L-/S-band 1.525-1.559; 1.6265-1.6605[4] 2.4835-2.5000; 1.6265-1.6100[5]

[1] The frequency band allocations shown are based on decisions by the International Telecommunication Union (ITU) and the Federal Communications Commission and for which the best "authority" is the respective Radio Regulations. The information shown, however, has been taken from Christensen (1994b) for the FSS and BSS and from Christensen (1994a) for the MSS. The frequency bands shown on the left (generally, before a semicolon) are for downlink transmissions; the frequency bands shown on the right (generally, after a semicolon) are for uplink transmissions. Further, the bands, as shown, may be divided into two or more contiguous sub-bands with secondary service or other designations for parts of the bands.

[2] These frequency bands are designated as unplanned. This means that a qualified, potential, satellite operator may obtain a frequency assignment and GSO location for a system essentially on a "first come, first served" basis, subject to satisfying the requirements of Articles 11 and 13 of the ITU Radio Regulations.

[3] These frequency bands are designated as planned. This means that a frequency assignment and associated nominal orbit location are reserved (guaranteed) for each member-country of the ITU, and a qualified, potential, satellite operator may use these resources, subject to National approval, without following the requirements of Articles 11 and 13 of the ITU Radio Regulations.

[4] These frequency bands are the so-called "traditional MSS bands" that are further divided into frequency sub-bands to provide AMSS, MMSS, and LMSS.

[5] These frequency bands were established at the World Administrative Conference-92 with the main users expected to be the LEO satellite operators; however, the bands are designated for all types of mobile satellite services.

4.10.1 Fixed-Satellite Service

As implied earlier, the fixed-satellite service was established to provide voice, data, and video services between fixed points, whereas transmissions intended for direct reception by the general public is a service that belongs to the broadcasting-satellite service, also known as the direct broadcast satellite (DBS) service. Table 4-5 shows the domestic satellites, both C-band and Ku-band, that provide fixed-satellite services as of August 1995. The table also shows the number and bandwidth of transponders (capacity) for each satellite, as well as the orbit location and operator. The Federal Communications Commission is the best source for information of this type, however, the information in Table 4-5 has been assembled from three other sources—Morgan and Petronchak (1994), Foley (1994), and Wilson (1993). Services that are available today include the following:

Telephone. One of the first commercial services provided by communication satellites was telephone service, primarily between the United States and Europe. Prior to the proliferation of fiber optic cables in the United States, satellites were used to provide some domestic, long-distance service. In 1990, voice service, including voice circuits conditioned to provide data traffic, was the third largest user of domestic satellite capacity following cable programming distribution and "broadcasting" services. The most notable domestic, telephone-service application today is the public telephone service provided to more than 100 villages in Alaska by Alascom, Inc. using the Aurora 2 satellite. This service clearly benefits a significant segment of rural society, providing basic telephone service and the attendant voice-circuit data services. Another communication satellite benefit to society, including the rural segment, is the flexibility available for traffic loading. This makes satellites an ideal capability for responding to traffic overloads or to damage, either accidental or intentional, of the terrestrial network.

Video program (cable and network television) distribution. The other commercial service provided by early communication satellites was distribution of television programming. According to Hudson (1990), approximately 40% of the C- and Ku-band transponders in use (in 1990) provide "satellite television service," a majority being the distribution of programming to cable systems. The remainder provide delivery of television programming to major network affiliates along with the distribution of syndicated programs and special news events. Noted earlier, there are several million home owners, mostly rural and those otherwise bypassed by cable services, who have TVRO terminals and receive programming intended for cable companies and broadcasting affiliates, as well as the pay-television services listed in Table 4-6 and many pay-for-service channels providing entertainment, world and regional/local news, financial news, weather information, sports news, syndicated programs, music, religious programs, home shopping, and more.

Table 4-5. Domestic Fixed-Satellite Service Capacity for the United States (as of August 1995)

OPERATOR	SATELLITE	C-BAND TRANSPONDERS		Ku-BAND TRANSPONDERS		ORBIT (degrees)
		Number	BW (MHz)	Number	BW (MHz)	
AT&T	Telstar 401	24	36	16	54	097 W
	Telstar 402R	24	36	16	54	089 W
COMSAT	SBS 2	---	---	10	43	071 W
	SBS 3	---	---	10	43	074 W
GE (with GTE)	Satcom C-1	24	36	---	---	137 W
	Satcom C-3	24	36	---	---	131 W
	Satcom C-4	24	36	---	---	135 W
	Aurora 2[1] (Satcom C-5)	24	36	---	---	139 W
	Satcom K-1	---	---	16	54	085 W
	Satcom K-2	---	---	16	54	081 W
	Spacenet 2	(out of service)	(out of service)	6	72	069 W
	Spacenet 3R	---	---	16	54	087 W
	Spacenet 4 (ASC 2)	12	36	6[2]	72	101 W
		6	72	---	---	
	ASC 1	(out of service)	(out of service)	6	72	128 W
	GStar 1	---	---	16	54	103 W
	GStar 2	---	---	16	54	125 W
	GStar 3	---	---	16	54	093 W
	GStar 4	---	---	16	54	105 W
Hughes	Galaxy 1R	24	36	---	---	133 W
	Galaxy 3R	24	36	8	54	095 W
		---	---	16	27	
	Galaxy 4	24	36	8	54	099 W
		---	---	16	27	
	Galaxy 5	24	24[3] & 36[3]	---	---	125 W
	Galaxy 6	24	36	---	---	074 W

Table 4-5. Domestic Fixed-Satellite Service Capacity for the United States (as of August 1995; continued)

Hughes (continued)	Galaxy 7	24	36	8	54	091 W
		---	---	16	27	
	SBS 4[4]	---	---	10	43	077 W
		---	---	4	110	
	SBS 5	---	---	10	43	123 W
		---	---	4	110	
	SBS 6[5]	---	---	19	43	095 W
TOTALS		306	10,692[3]	298	14,865	

[1] Two-thirds of the capacity of this satellite is owned by Alascom, Inc. and is used to provide domestic telephone service, the Alaskan Television Network, and emergency messages.

[2] Three transponders (19, 21, and 23) are inoperative.

[3] Characteristics available for the Galaxy 5 satellite do not specify the number of transponders with 24-MHz bandwidth nor the number of transponders with 36-MHz bandwidth. Therefore, the assumption has been made that 12 transponders have 24-MHz bandwidth, and 12 transponders have 36-MHz bandwidth.

[4] The functions of this satellite were replaced by Galaxy 7 in January 1993, at which time SBS 4 was moved to its present location. Hughes may sell the satellite.

[5] The functions of this satellite were replaced by Galaxy 4 in 1993, at which time SBS 6 was moved to its present location as an in-orbit spare.

Table 4-6. Typical Pay-Television Services Available Via Satellites

SERVICE NAME	SATELLITE USED
Home Box Office	Galaxy 5 and 7
Cinemax	Galaxy 1R and 5
Showtime	Satcom C-3 and C-4
The Movie Channel	Satcom C-3 and C-4
The Disney Channel	Galaxy 1R and 5
The Nostalgia Channel	Galaxy 1R
Encore	Galaxy 1R
Bravo	Satcom C-4
American Movie Classics	Satcom C-4
Independent Film Channel	Galaxy 6
TNT	Galaxy 5

Radio and special-program distribution. Most radio networks have switched to communication satellites for distribution of their network programming because of flexibility in using transponder time, improved audio quality, and reduced transmission costs. There are actually two types of radio programming that are being distributed via satellite:

1) the "normal" news and programs delivered to network-affiliated stations; and

2) a type of single-format programming for "automated" radio stations that requires the local station to provide only local advertising at scheduled break-times. An example would be a single-format music station that broadcasts only classical, jazz, country/western, or easy-listening music.

Satellite distribution of radio programming provides clear benefits for rural communities. It can be a way to minimize labor costs and other expenses for small and/or new stations helping them to compete with larger, more-established stations. It also can provide a way to offer diversified programming not otherwise available from or profitable for local stations.

Another type of satellite-delivered programming is that used in many stores and offices as background music. Muzak®, 3M Sound Products, Music Network, and Seeburg Music Network are examples of music networks that offer this service and may also offer the opportunity for advertising and/or promotional announcements.

News gathering. Communication satellites are used not only to distribute programming to cable systems and network affiliates; they also are playing an increasingly important role in developing news programming. This role often is referred to as satellite news gathering (SNG). A typical (and note worthy) example of this service is the ability of TV viewers around the world to view live coverage of Olympics events and major sporting events. Another example is, again, the ability of world-wide television viewers to witness live coverage of major news events, such as the Persian Gulf War. This service also offers the opportunity for new-worthy events to be reported by small television stations and from rural locations. Thus, SNG is a communication service that provides benefit to rural communities both by bringing news to them and as an opportunity for news from their communities to be reported, thereby helping the rural communities to be "informationally integrated."

Distance learning. Many educational opportunities are available via communication satellites. Some examples are the National Technological University, based in Fort Collins, Colorado, using BSS satellites; The Discovery Channel on Satcom C-4 (East) and Galaxy 5 (West); The History Channel on Satcom C-3; The Learning Channel on Satcom C-3; and the Mind Extension University on Galaxy 5. According to Manasco (1994), the Mind Extension University (the "flagship enterprise" of Jones Education Networks, headquartered in Englewood, Colorado) has about 5,000 students in degree programs and about 40,000 course enrollees. This type of service, providing accredited college and graduate-level courses via cable systems and home TVROs, clearly offers significant opportunities to rural communities and residents. Additionally, there are numerous state and other universities offering educational opportunities via satellite, e.g., Indiana and Purdue, described in Communications News (1995).

4.10.2 Broadcasting-Satellite Service

Even though direct-to-home (DTH) television reception has been available for many years using signals broadcast in the fixed-satellite service frequencies, the broadcasting-satellite service frequencies are just beginning to be used to provide DTH services. Aside from the different frequency allocations for the BSS (compared with the FSS), a key distinction of the BSS satellites is the ability to transmit with much higher power (typically, higher by an order of magnitude or more) than FSS satellites. This allows the use of much smaller and lower-cost receiving antennas (typically on the order of 15-25"). These small antennas are not only inexpensive to purchase, but they also are much easier and less expensive to install. The United States has been allocated eight orbital positions by the ITU for BSS. An example of this type of service is the newly offered DirecTv® television services, with 150 channels, that uses two high-powered Hughes 601 satellites, DBS 1 and 2, collocated in orbit at 101° W. Other satellite operators expected to be offering BSS (or DBS) services in the near future include EchoStar Communications Corporation and Tempo DBS, Inc., a subsidiary of cable company Tele-Communications, Inc. (TCI). The potential benefits to rural communities and users even exceed those described earlier for services provided by the FSS.

4.10.3 Mobile-Satellite Service

As often noted, the ultimate goal in providing communication services is the ability to communicate anywhere, at any time, with anyone or anything according to individual needs. To a limited extent, this has been possible using GSO satellites, but the cost for equipment as well as for the service is very high. These inhibiting factors are expected to change dramatically with the introduction of new LEO[5] satellite systems. Existing and proposed mobile satellite systems identified by Cochetti (1994) are briefly discussed below.

Iridium. A new mobile satellite system, proposed and designed by Motorola, that is expected to comprise 66 satellites at an altitude of 484 miles (780 km). The system is projected to consist of 11 satellites in each of six orbital planes. Each satellite is expected to have direct links to adjacent satellites that would permit calls to hop from satellite to satellite as required by the originating locations and destinations. The system's satellites would project a grid of beams (cells) onto the Earth's surface somewhat similar to, but larger than, the grid of cell sites in a cellular telephone network.

[5]The term low-Earth orbit (LEO) is defined by Larson and Wertz (1992) as an orbit below 621 miles (1000 km; below the Van Allen radiation belts) contrasted with GSO where the orbit is about 22,224 miles (35,787 km) above mean sea level. This is the meaning intended here. Other types of orbits include medium-Earth orbits (MEOs), and highly-elliptical orbits (HEOs).

AMSC/TMI. American Mobile Satellite Corporation (AMSC; a publicly traded company) presently offers a satellite-based mobile data service in the United States. AMSC plans to offer voice and data services, using its own dedicated L-band GSO satellite, to a wide range of target markets, serving land mobile, maritime, aeronautical, and fixed-site applications. The focus, however, is expected to be land-mobile cars and trucks. AMSC's customers will be value-added resellers, like cellular telephone service providers, who will integrate AMSC's services into their own mobile communications services. (TMI Communications Co. Ltd. is a Canadian mobile satellite service licensee who will partner with AMSC to serve the Canadian market with their own satellite called MSAT.)

OmniTracs. Since the mid-1980's, Qualcomm has been offering a unique mobile data (only) communications service, primarily intended for long-haul truckers, using the code-division multiple access (CDMA) spread spectrum modulation technique and capacity on Ku-band satellites licensed for FSS. This innovative approach to mobile satellite communications is called OmniTracs, which is the largest mobile satellite communications system operator in the world, in terms of mobile terminals in use.

Globalstar. Loral Corporation and Qualcomm have formed a partnership called Loral Qualcomm Satellite Services intending to build and launch a LEO system to provide mobile voice service. The mobile satellite system will have 48 satellites deployed in eight orbital planes at an altitude of 878 miles (1,414 km). The company now is seeking exclusive service agreements with existing cellular or fixed, wireline service operators to extend the Globalstar service to their local and regional subscribers.

Odyssey. TRW Space and Electronics Group is proposing a mobile satellite system that would use 12 satellites—four in each of three 50°-inclined circular orbits at an altitude of 6430 miles (10,354 km), so-called medium-Earth orbits. This system, known as Odyssey, would be "high in the sky," which TRW claims is important for connectivity into areas where there are trees, buildings, and mountains. Compared with LEO systems, the Odyssey system would require significantly fewer satellites to provide near-global coverage; six for "minimal" coverage and 12 for complete coverage, with many areas having dual coverage.

Ellipso. A company called Mobile Communications Holding, Inc. proposes to deploy a system of highly elliptical orbiting satellites called Ellipso. The system initially would contain six satellites but eventually the number would be increased to 24 satellites in three elliptical orbits. Two of the orbits would be highly inclined at 116.6° and one would be equatorial, thereby offering good coverage to subscribers in the northern hemisphere (and extending through most of the southern hemisphere). The two inclined orbits would have apogees of about 4844 miles (7,800 km) and perigees of about 323 miles (520 km). The equatorial orbit would have an apogee of about 4844 miles (7,800 km) and a perigee that would range from about 2484-4844 miles (4,000-7,800 km).